e^- Beam Dump eXperiment(s) to Search for Light Dark Matter

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1307.6554 & 1403.6836

& **The BDX Collaboration**

1406.3028

Theoretical Perspectives on New Physics at the Intensity Frontier
Victoria, BC Sept. 12, 2014

Overview

- a "light" dark sector?
- why electron beams?
- what can be done *today*?
- ... *tomorrow*?
- BDX progress

Q: Does "Light" Make Sense?

Naive guess: overclosure?

$$\langle \sigma v \rangle \sim \frac{\alpha \alpha_D m_\chi^2}{M_{med}^4} \implies \Omega_\chi \gg (\Omega_{DM})_{obs.}$$

..... implies light mediator

$$m_\chi > M_{med} \ , \ \langle \sigma v \rangle \sim \frac{\alpha \alpha_D}{m_\chi^2} \implies \frac{\Omega_\chi}{\Omega_{DM}} \sim 10^{-3} \left(\frac{\alpha}{\alpha_D} \right)^2 \left(\frac{m_\chi}{100 \text{ MeV}} \right)^2$$

Naive guess: ruins CMB?

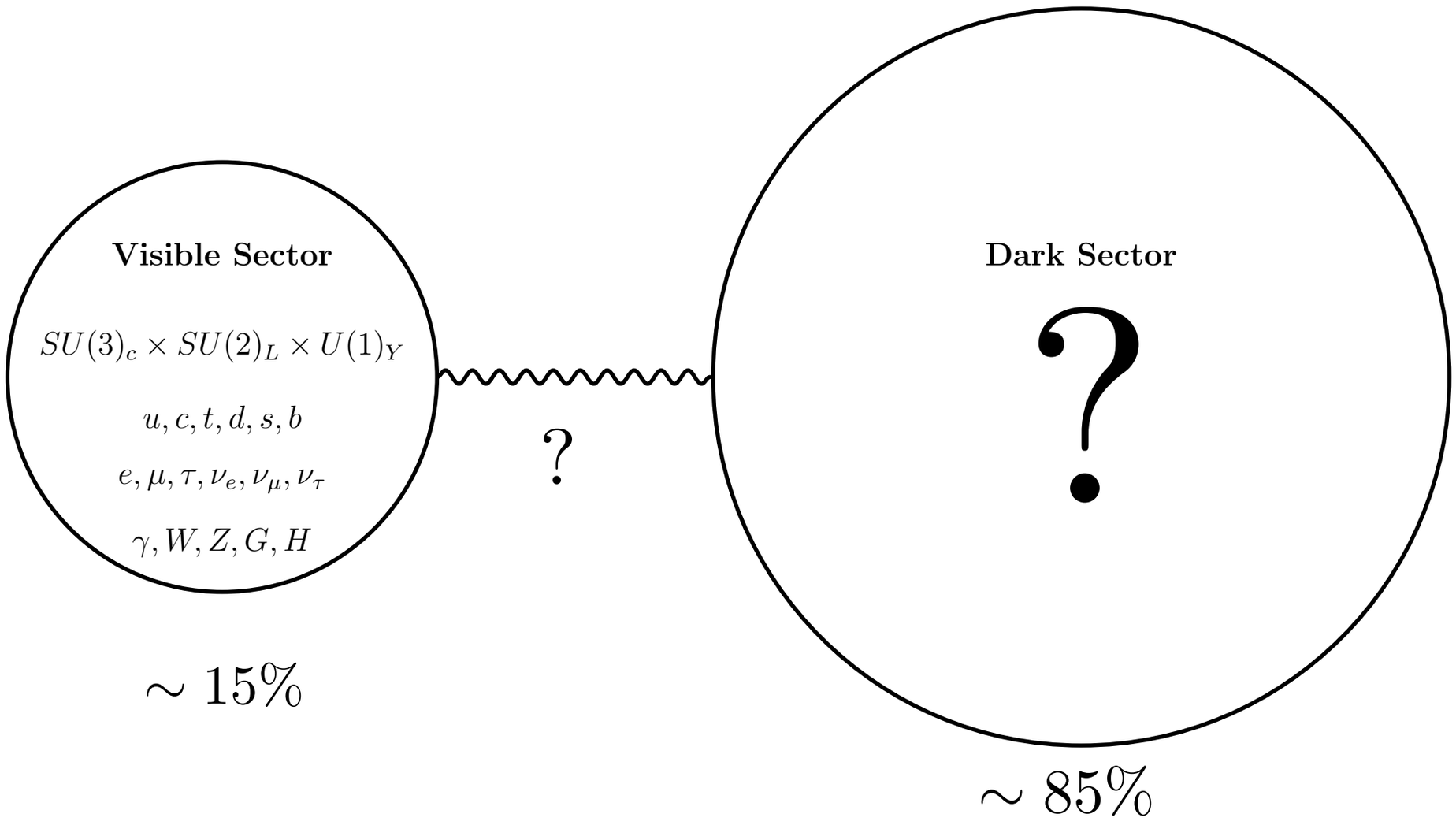
$$\Omega_\chi = \Omega_{DM} \implies \sigma_{\chi\chi \to \ell\ell} < 10^{-5} \left(\frac{m_\chi}{\text{MeV}} \right) \sigma_{thermal}$$

$$\Omega_\chi < \Omega_{DM} \implies \left(\frac{\Omega_\chi}{\Omega_{DM}} \right) < 10^{-3} \left(\frac{m_\chi}{100 \text{ MeV}} \right)$$

Highly model dependent

Q: Does "Light" Make Sense?

A: *Yes! (too) many possibilities…*



If there are light particles, let's find them!

Simplified Model

Familiar starting point

$$\frac{\epsilon}{2} F_{\mu\nu} F'_{\mu\nu} + \frac{m_{A'}}{2} A'^{\mu} A'_{\mu} + \bar{\chi}(i\not{D} + m_\chi)\chi + \cdots$$

Most of this talk

$$m_\chi, m_{A'} \sim \mathrm{MeV} - \mathrm{GeV}$$

$$\epsilon \sim 10^{-5} - 10^{-2}$$

$$\alpha_D \sim 10^{-2} - 1$$

Great for fixed target searches

Simplified Model

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Great for fixed target searches

$U(1)_D$ **breaking sector always there!**

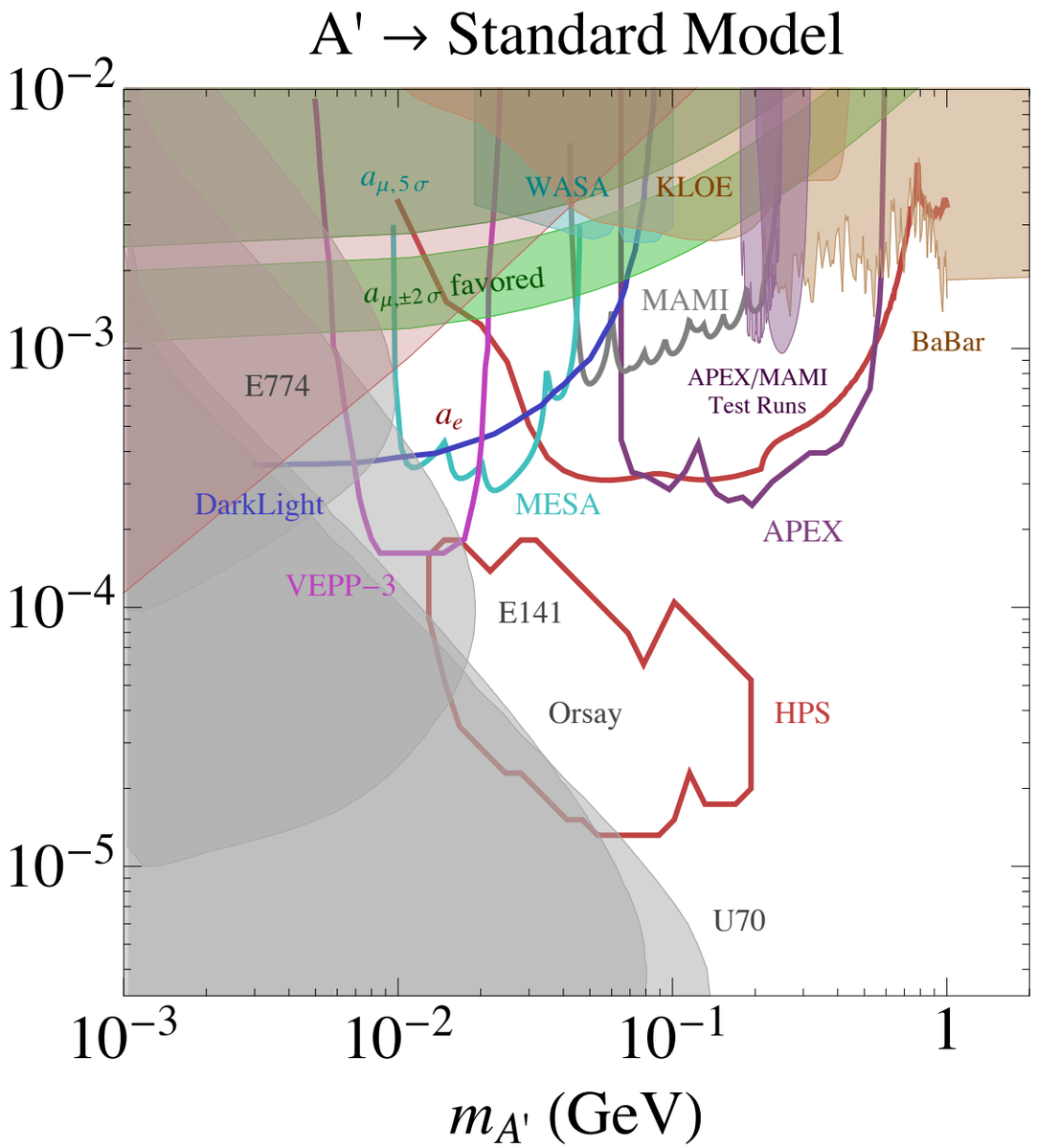
Generic $\mathcal{O}(1)$ **DM mass splitting**

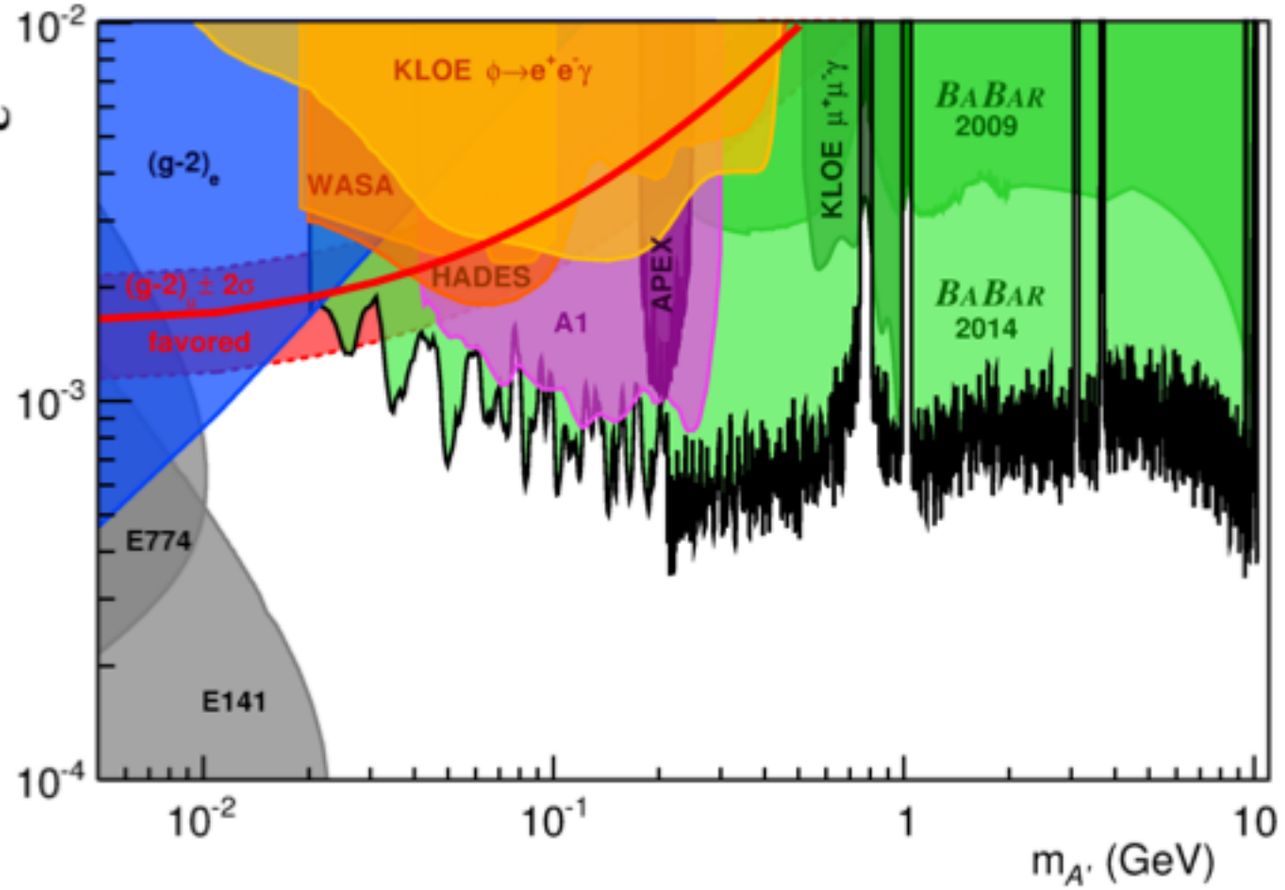
$$H_D \overline{\chi^c} \chi \to v_D \overline{\chi^c} \chi$$

$$\Delta \sim m_\chi$$

Identical model, Rich pheno, CMB 100% OK!

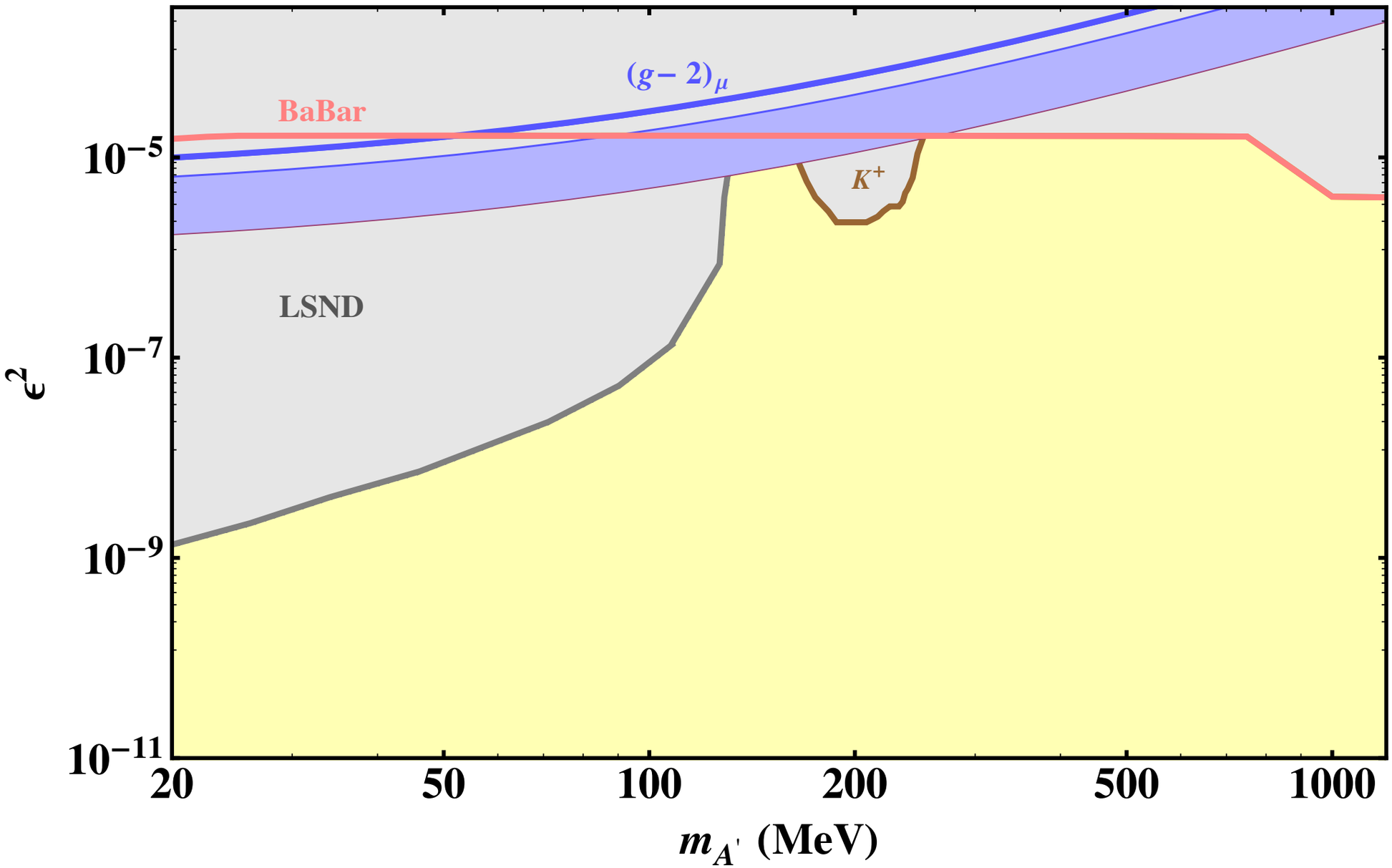
If A' Decays to the SM





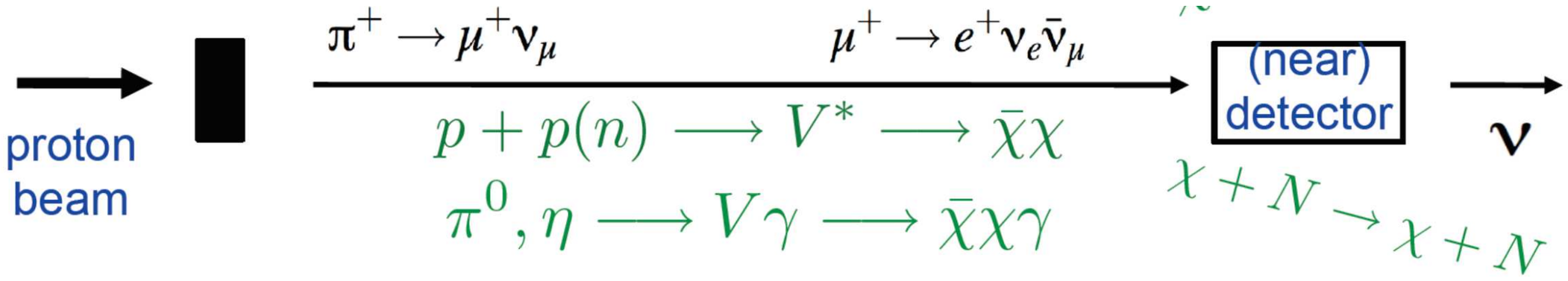
… much harder for *invisible* decays

If *A'* Decays *Invisibly*



Only the g-2 curves are totally model independent

A' Decays Invisibly: Neutrino Factories



Pioneering searches *w/* MiniBooNE, LBNE, MINOS NOvA...

DM produced via nuclear physics, scatters downstream

(Batell, Pospelov, de Niverville, McKeen, Ritz, Dharmapalan...)

However:

Designed to make neutrinos = large NC backgrounds

Large ~ 100 m - km baseline degrades acceptance

Proper search expensive, requires dedicated beam time

Overview

- a "light" dark sector?
- why electron beams?
- what can be done *today*?
- ... *tomorrow*?
- BDX progress

Why Electron Beams?

Beam backgrounds: negligible(!)

Parasitic: existing beams & detectors

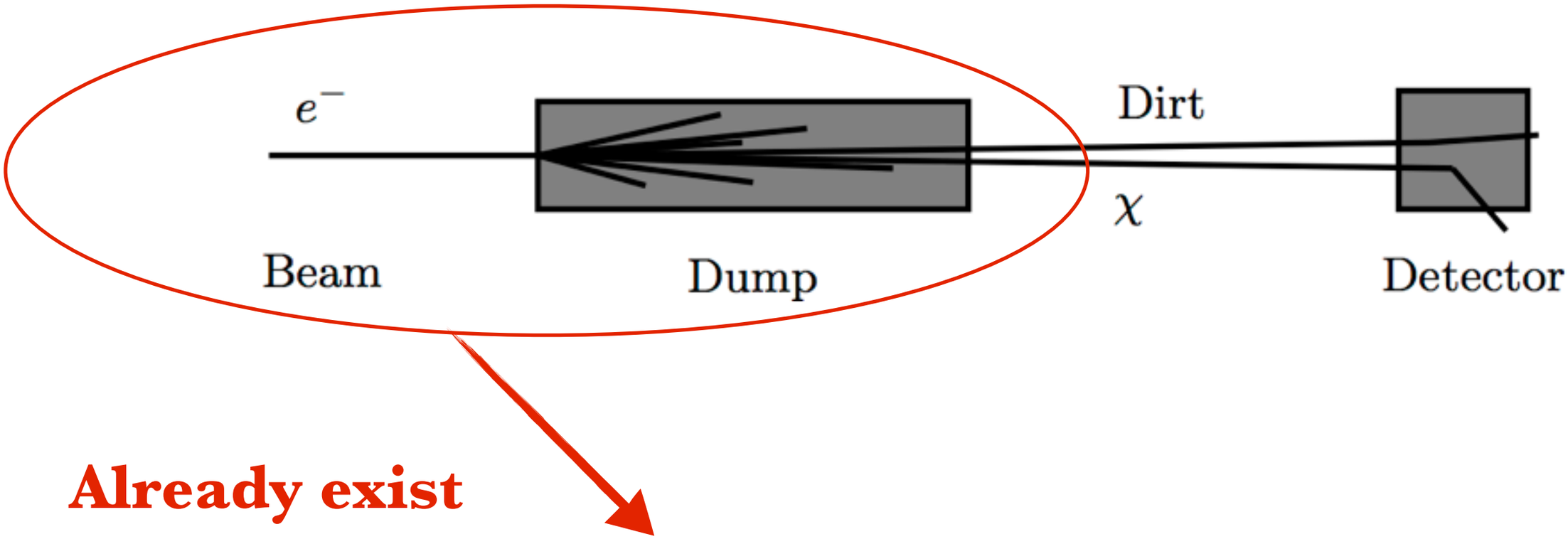
Discount physics: small & cheap

High acceptance: nearby detector & forward kinematics

Cosmic backgrounds: beatable & reducible

Complement neutrino factories & visible searches

How to Search
Ingredients



Already exist

Electron beam (few-100) GeV, continuous or pulsed

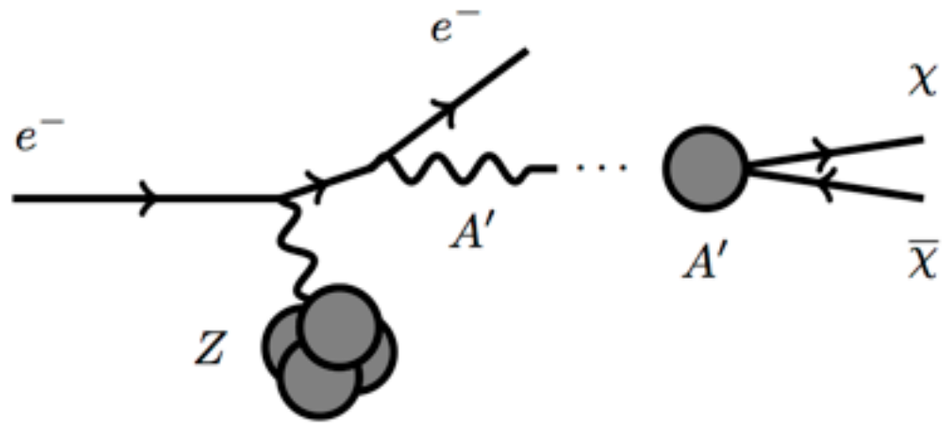
Beam dump & dirt ~ 10 m, range out beam BG

Just need

Small Detector for NC scattering: oil, plastic, LAr-TPC...

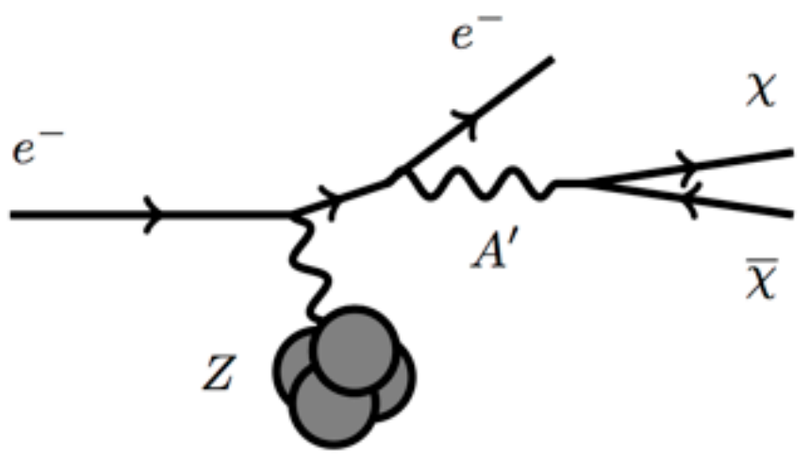
How to Search
Production

$m_{A'} > 2m_\chi \implies$ **on-shell A'-strahlung**



$$\sigma \sim \frac{\epsilon^2}{m_{A'}^2}$$

$m_{A'} < 2m_\chi \implies$ **off-shell radiative**



$$\sigma \sim \frac{\alpha_D \epsilon^2}{m_\chi^2}$$

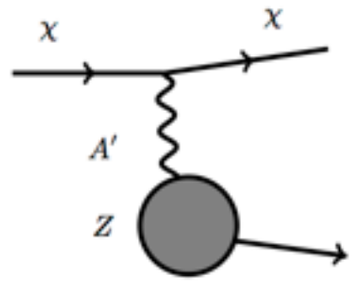
A' gets large fraction of beam energy

How to Search

Detection $\Delta = 0$

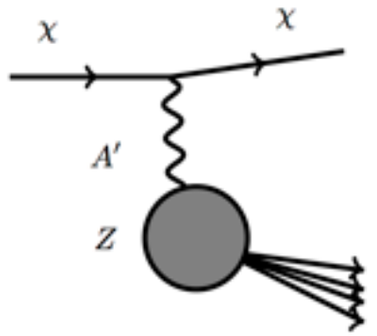
Coherent Nuclear

Low recoil energies, light mediator
Z^2 enhancement, form factor



Inelastic hadro-production

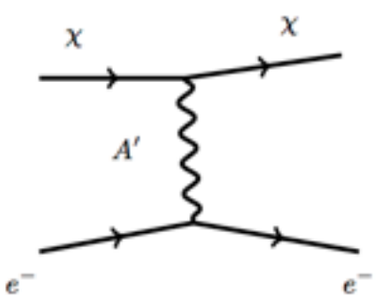
High Q transfer



$\pi, K \cdots$

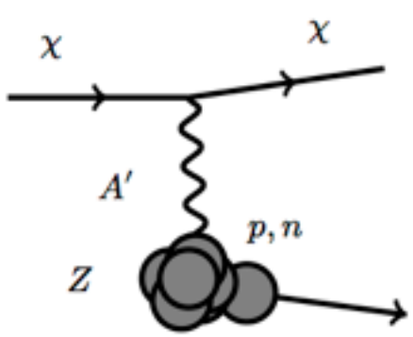
Electron Scattering

Low recoil energies, light mediator



Quasi-elastic Nucleon

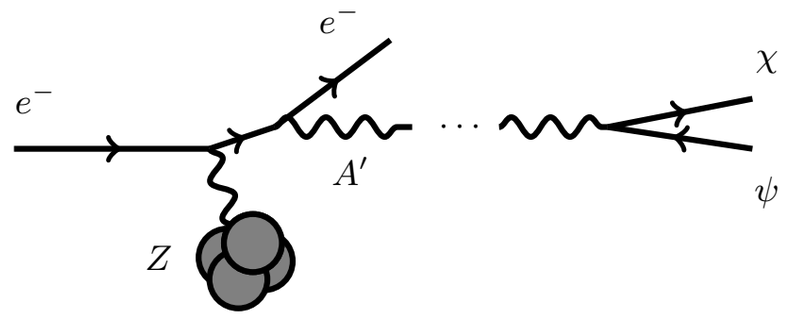
Higher recoil energies > 10s MeV,



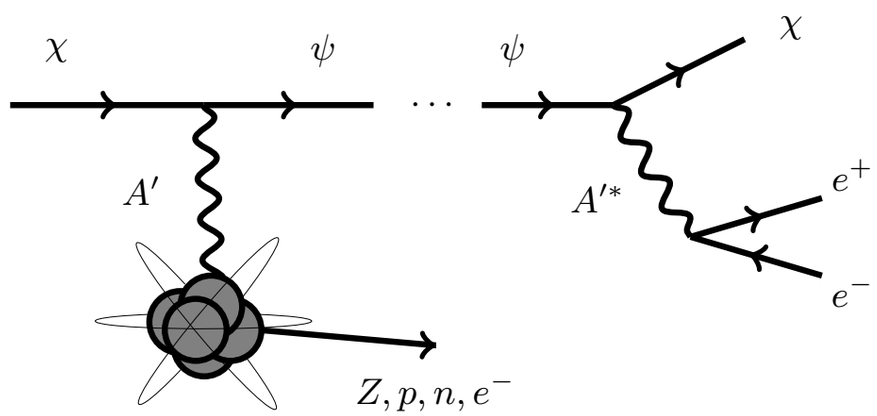
How to Search

(Inelastic) Detection $\Delta > 0$

A' produces both eigenstates (beam dump)



DM upscatters into excited state

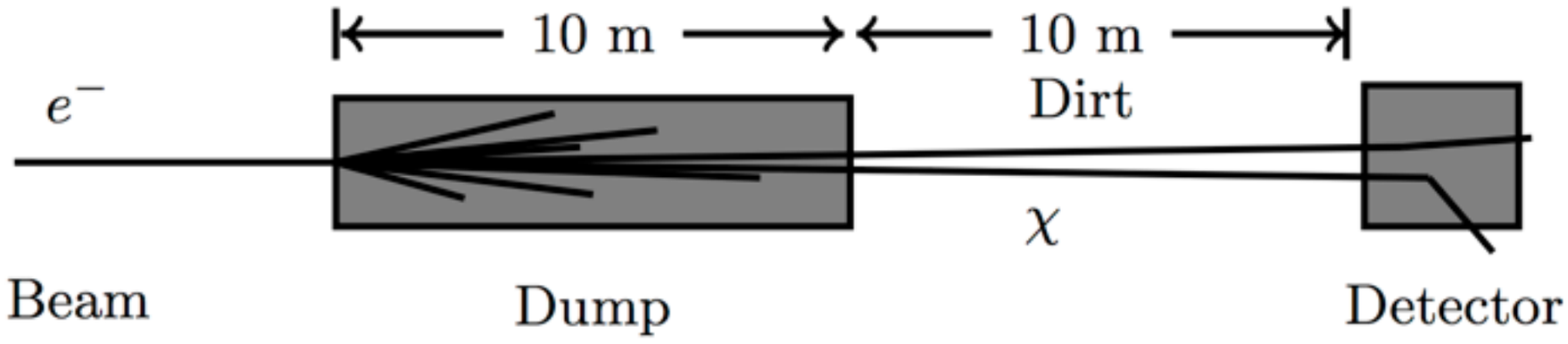


Excited state decays promptly
Releases ~ GeV energy

$$\Gamma(\psi \to \chi\, e^+e^-) = \frac{8\epsilon^2\alpha\alpha_D\Delta^5}{15\pi m_{A'}^4} + \mathcal{O}(\Delta^6)$$

$$\ell = c\tau \simeq 0.01\text{cm}\left(\frac{\gamma}{2}\right)\left(\frac{10^{-3}}{\epsilon}\right)^2\left(\frac{0.1}{\alpha_D}\right)\left(\frac{50\text{ MeV}}{\Delta}\right)^5\left(\frac{m_{A'}}{50\text{ MeV}}\right)^4$$

Basic Concept
Layout



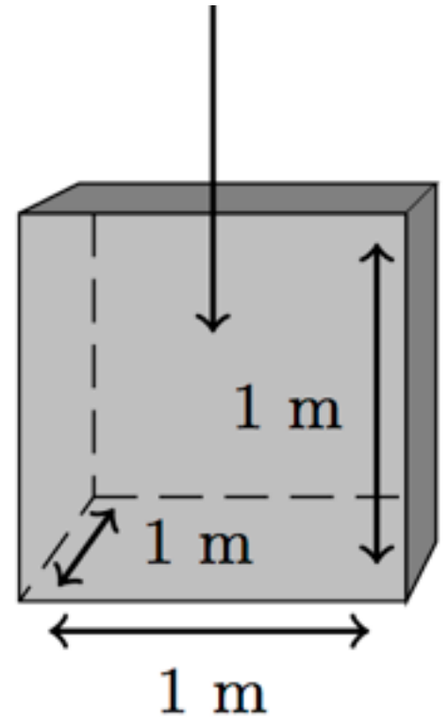
12 GeV (pulsed?)

Average current ~ $80\mu A$

10^{22} EOT (~ 1 yr.)

(Duty cycle ~ 10^{-4} , live-time ~ 10^3 s)

Fiducial volume $= 1\text{m}^3$



Oil based detector (CH_2)*
Depth = 15 m.w.e.

Basic Concept

Beam Correlated Backgrounds

Neutrinos from beam π/μ

Nuclear recoil cut $E_{recoil} > 10$ MeV

$(0.1 - 1)$ BG event per $10^{22}\, e^-$

Consistent with SLAC mQ rates

Ejected "Fast" Neutrons

$E_n < 10\,\mathrm{MeV}$, below cuts

$\Longrightarrow$ **Beam backgrounds very small**

Basic Concept

Beam Uncorrelated Backgrounds

Cosmic muons

Decays in flight ~ 0.005 Hz (veto)

Stopped decays ~ 100 μs cut (veto)

Cosmogenic neutrons

$$\Phi(E > 10\ \mathrm{MeV}) \approx 2 \times 10^{-2} \mathrm{m}^{-2} \mathrm{s}^{-1}$$

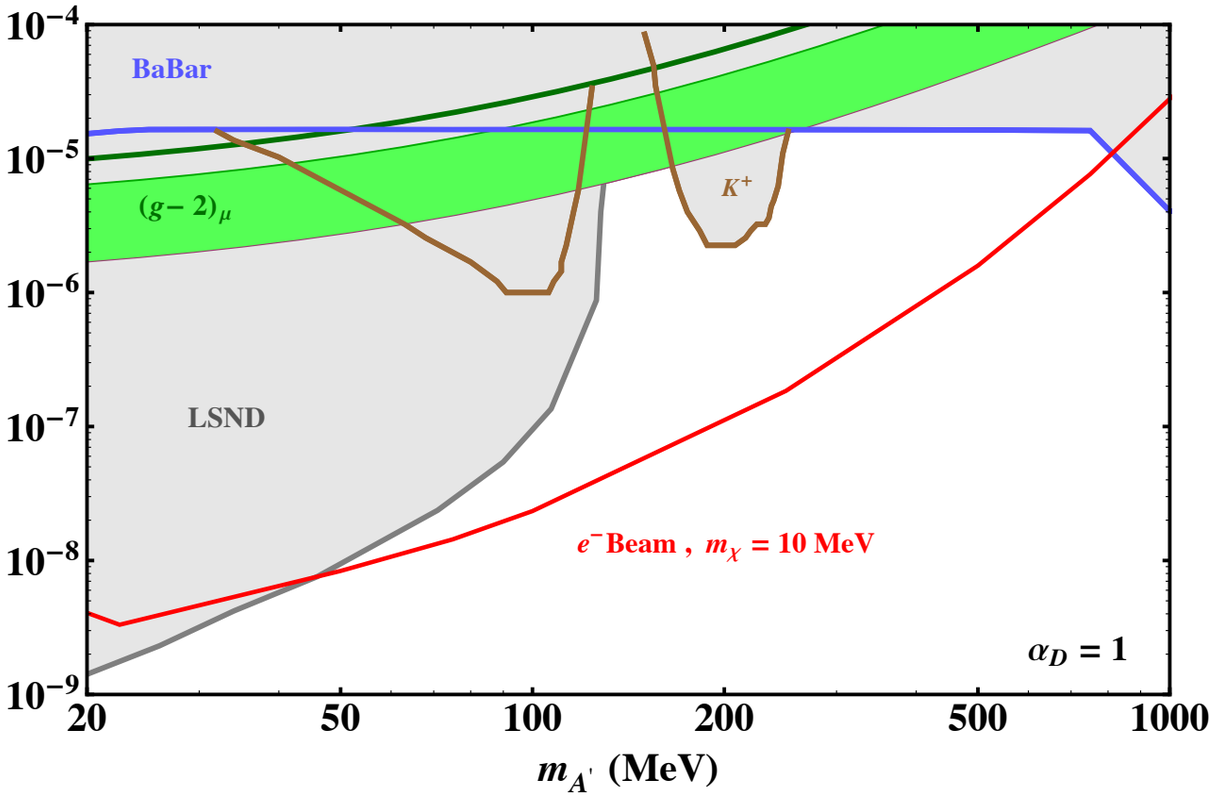
Consistent with CDMS-SUF (~ 10 m.w.e)

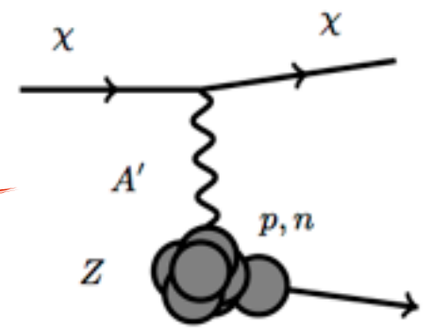
Pulsed beam ~ livetime 10^3 s , $\mathcal{O}(10)$ cosmic BG events

$\Longrightarrow$ ***Small, Measurable***

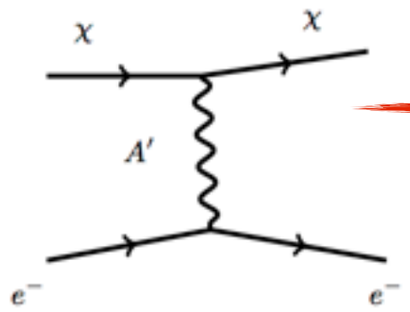
Sensitivity ~ 10 event signal yield

Basic Concept

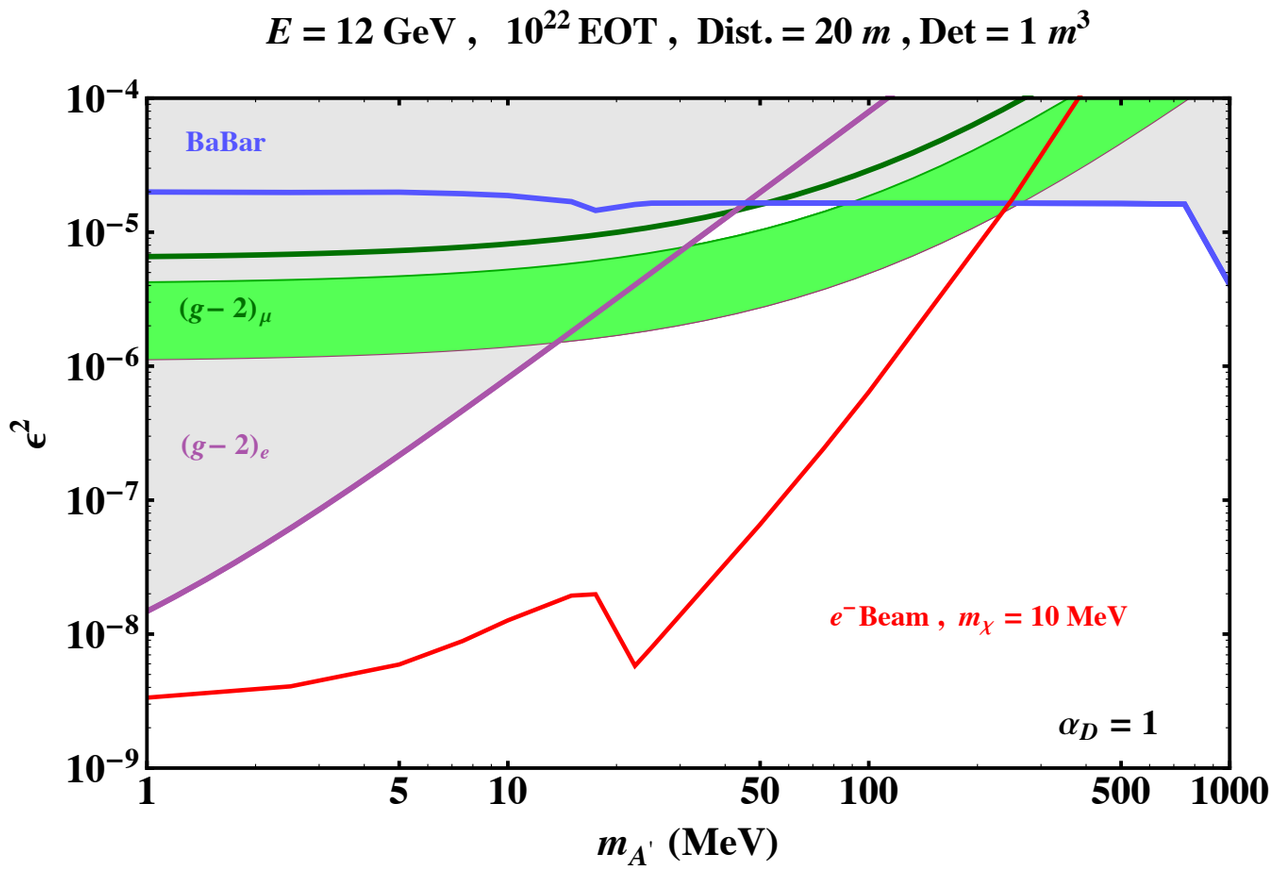




quasi-elastic nucleon



electrophilic $\Delta = 0$



Overview

- a "light" dark sector?
- why electron beams?
- what can be done *today*?
- … *tomorrow*?
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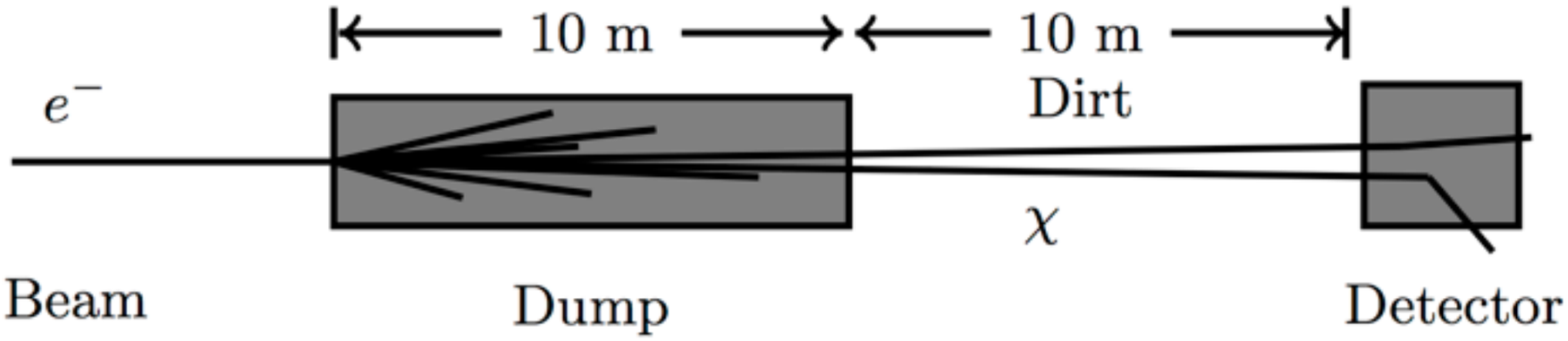
What Can Be Done *Today*?

JLab CEBAF



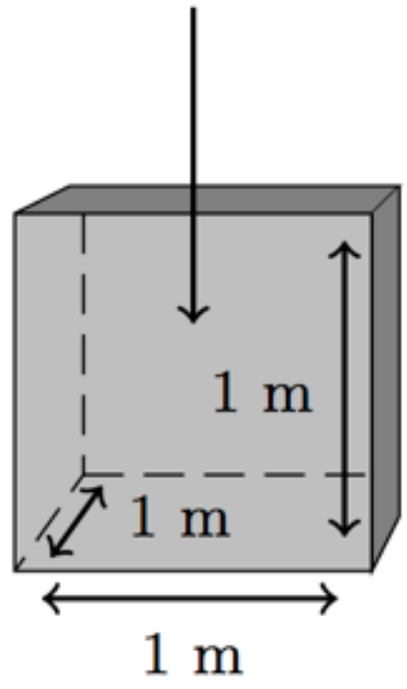
Continuous wave 12 GeV

Aluminum beam dump

$80\mu A \implies \sim 10^{22}$ Electrons/Yr.

No neutron rejection (veto muons)
$N_n \sim 400,000$, Systematics $\sim 2.5\%$

Sensitivity ~ 20,000 signal events



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What Can Be Done *Today*?

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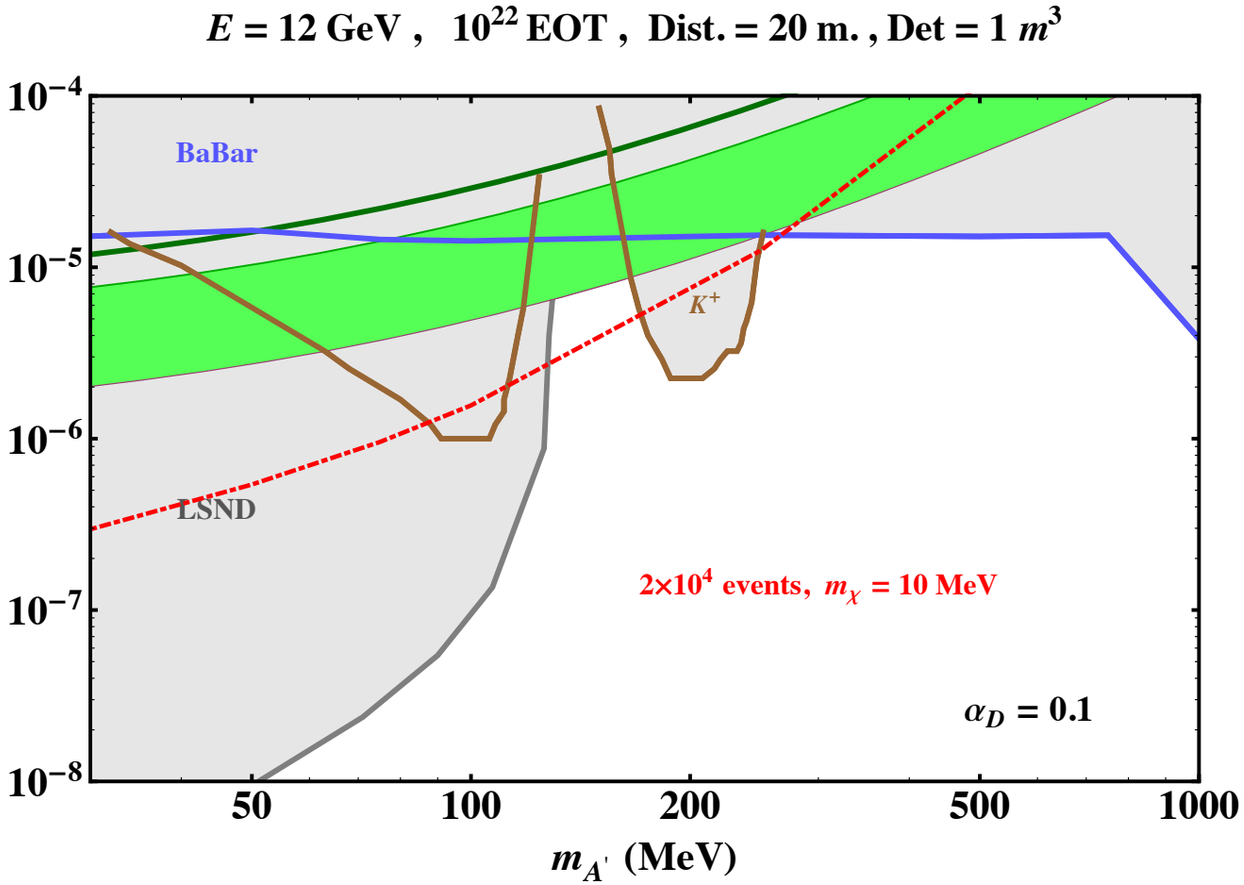
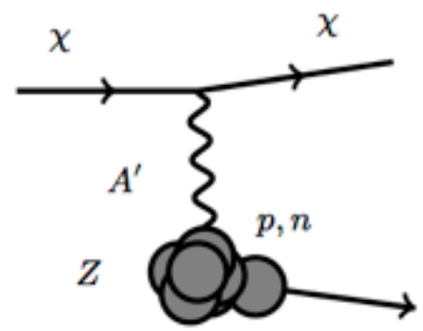




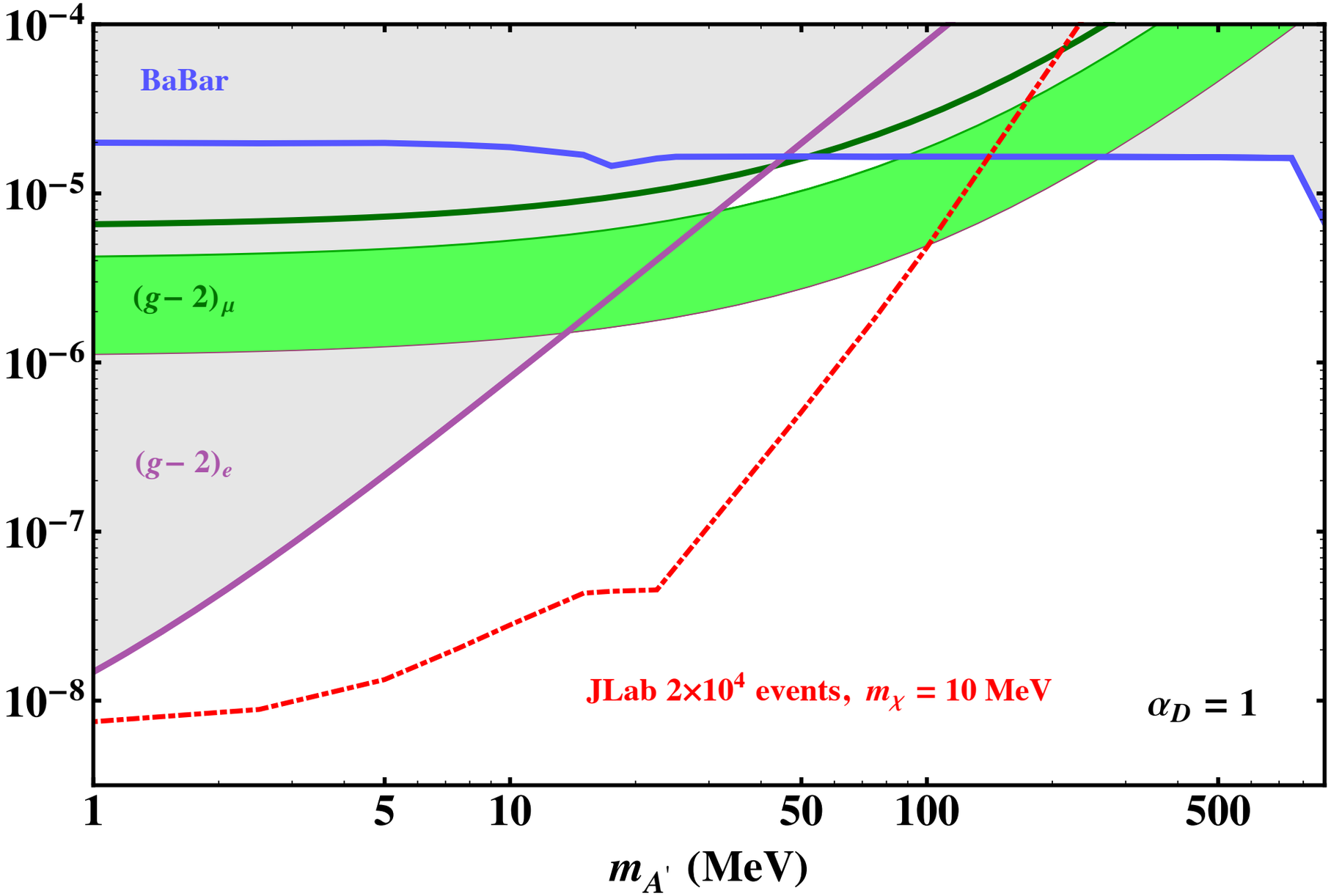
Quasi-elastic nucleon , CW beam

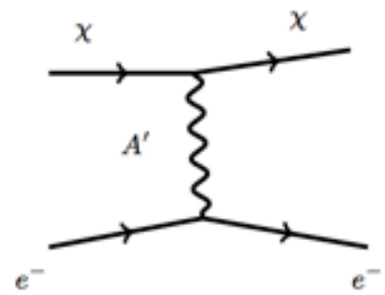
$$\Delta = 0$$

What Can Be Done *Today*?

JLab CEBAF

E = 12 GeV (JLab) , 10^{22} EOT , Dist. = 20 m. , Det = 1 m^3





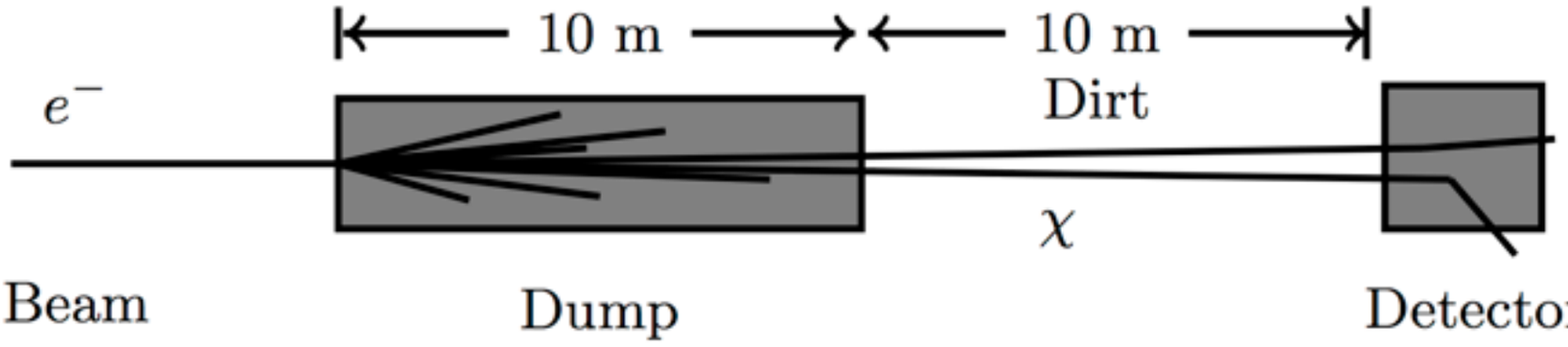
Electrophilic scattering, CW beam $\Delta = 0$

Overview

- a "light" dark sector?
- why electron beams?
- what can be done *today*?
- … *tomorrow*?
- BDX progress

Around the Corner 1

Some BG reduction (JLab)



Goal:

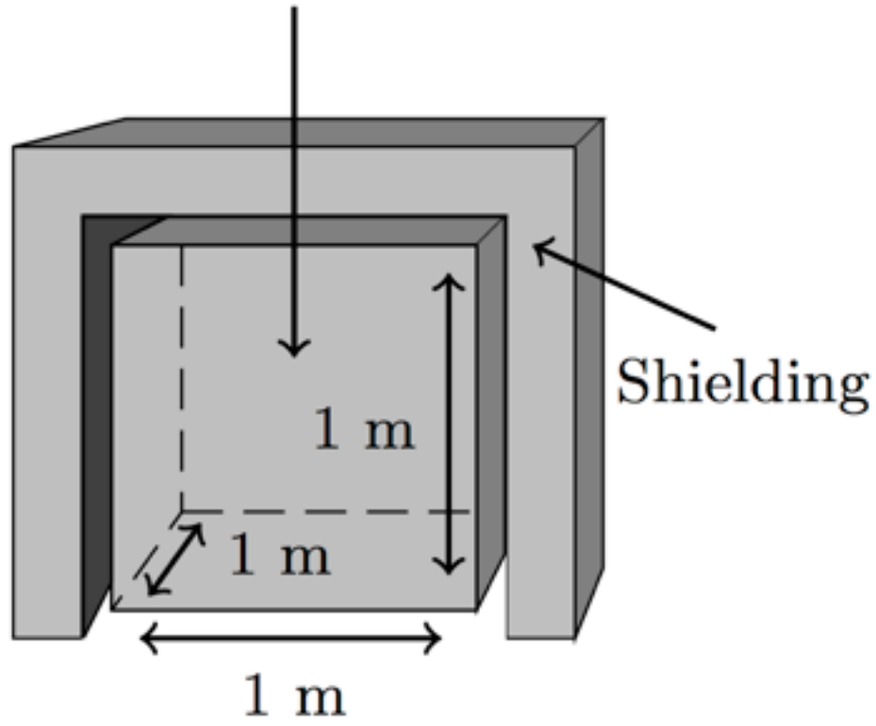
95% cosmic neutron reduction
Comparable to CDMS-SUF

2.5 % systematics (*n* flux)

Sensitivity ~ 1000 event signal yield

Need one/some:

Active neutron veto
Neutron moderator
Directional information



Oil-based, cubic-meter fiducial
Depth ~15 m.w.e

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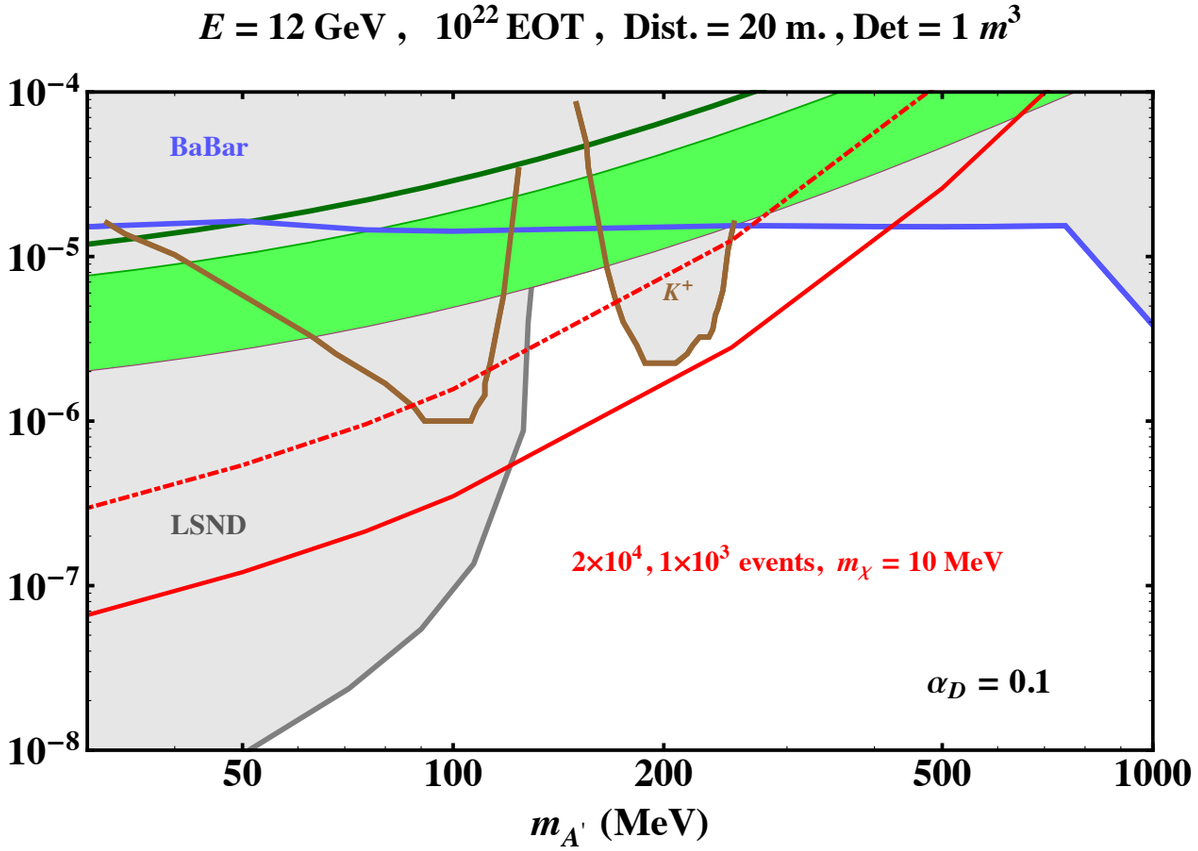
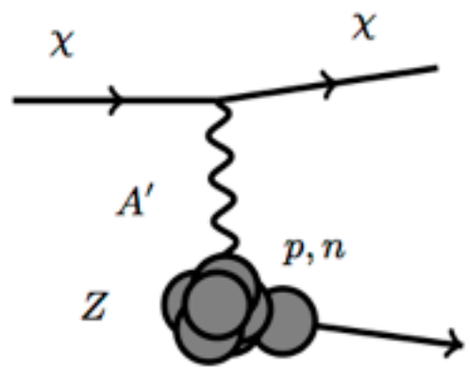
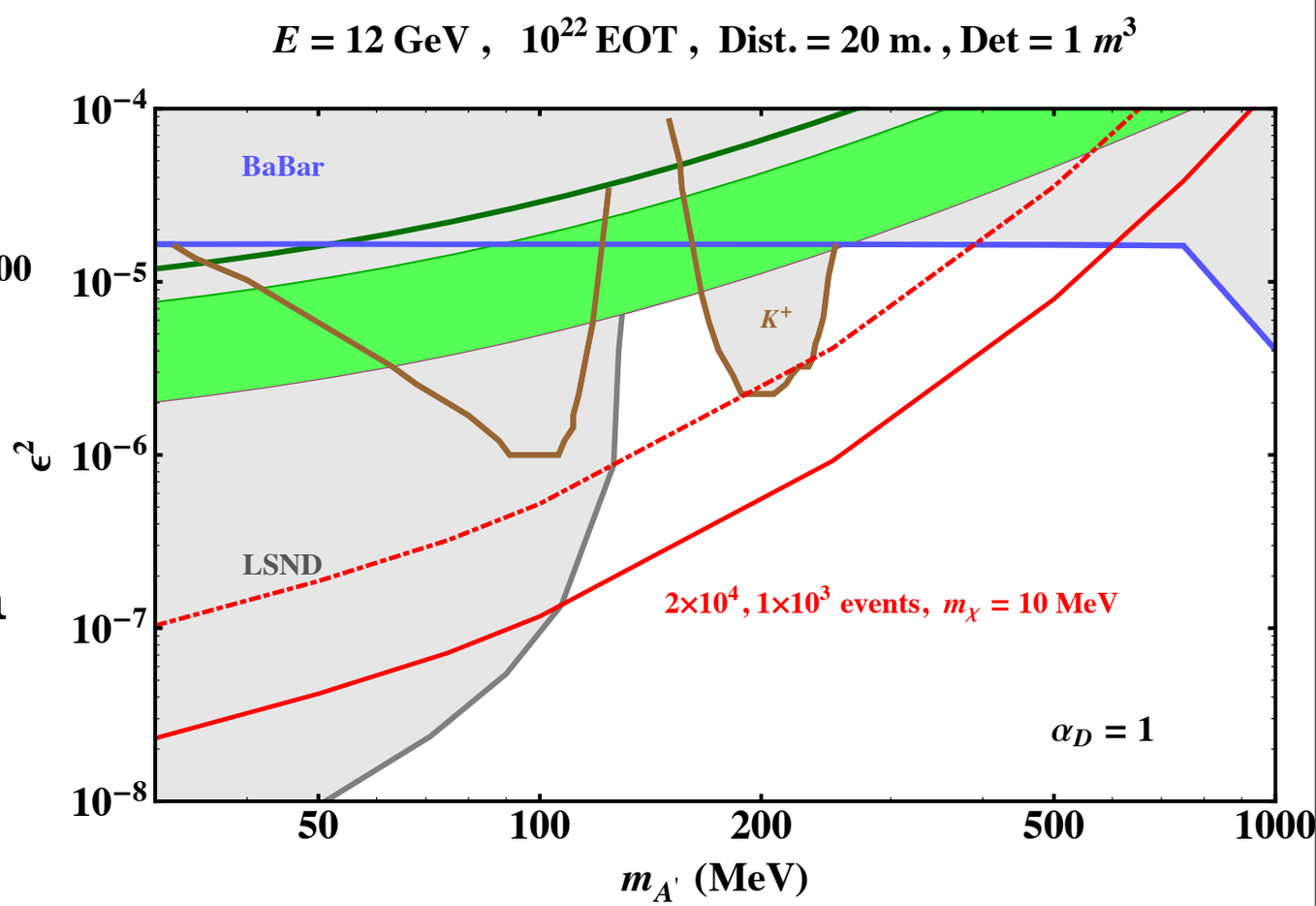




Quasi-elastic nucleon , CW beam

$$\Delta = 0$$



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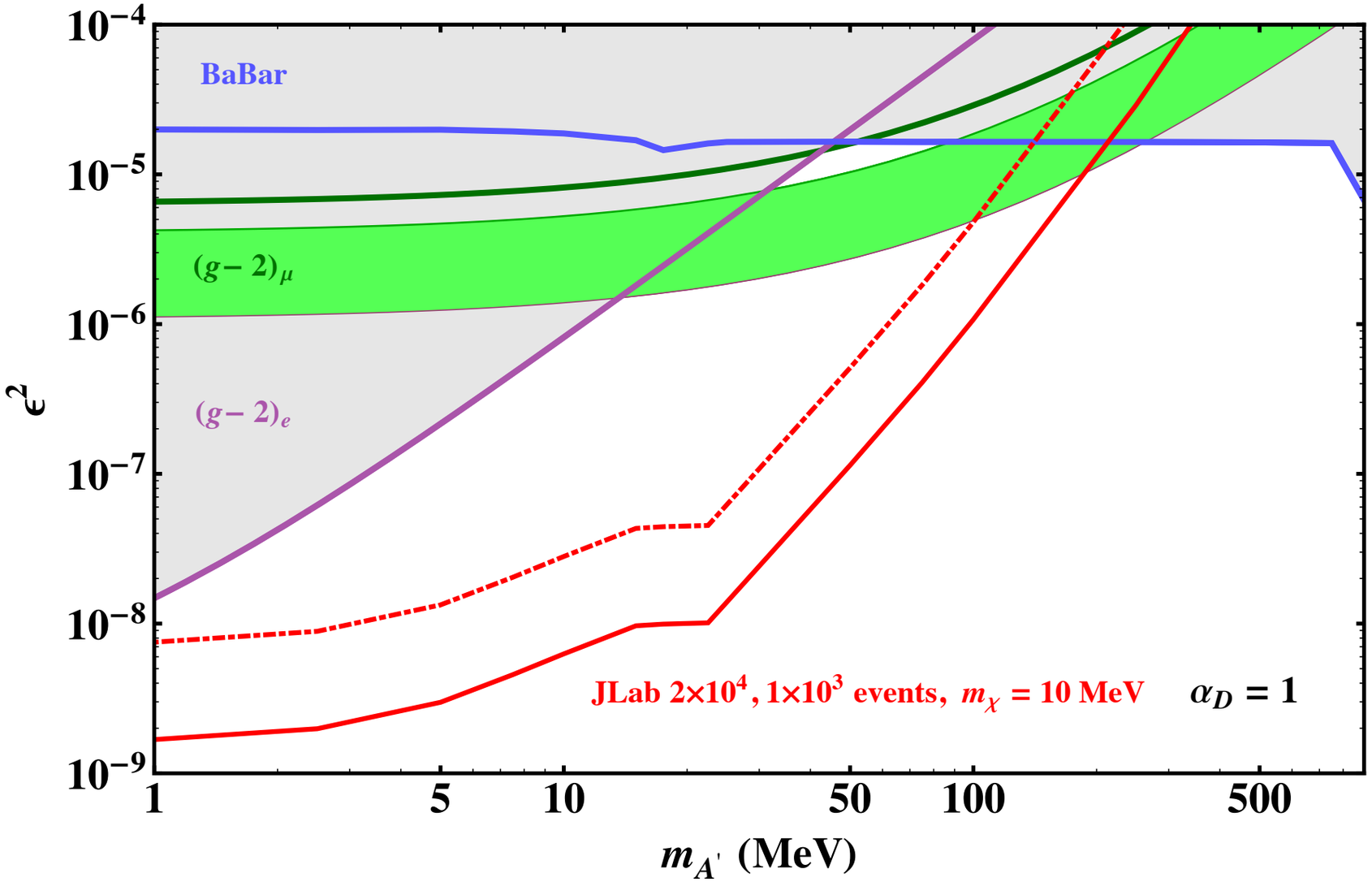
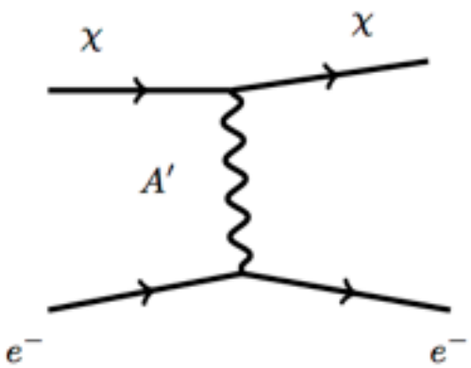
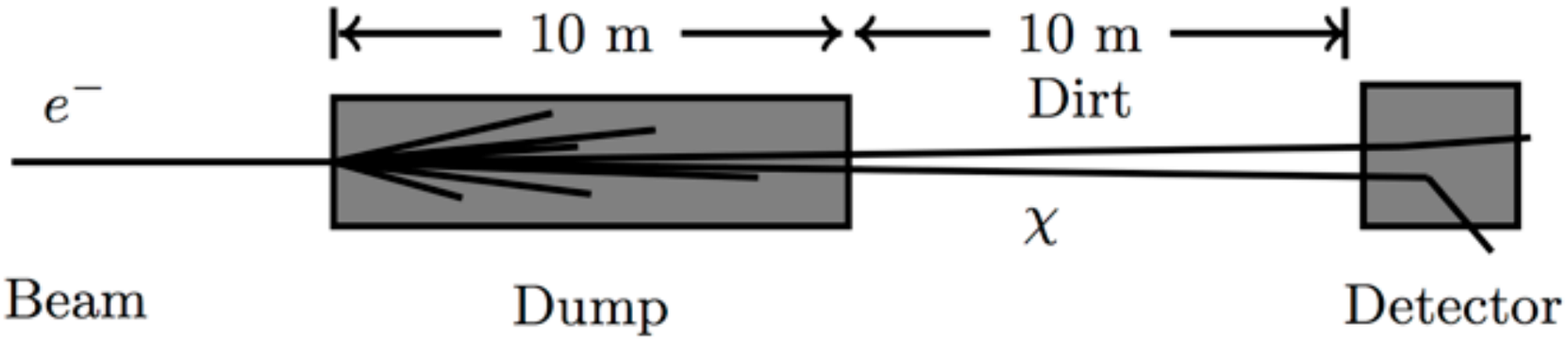




Electrophilic scattering, CW beam $\Delta = 0$

Around the Corner 2

Aggressive BG reduction (JLab)



Goal:

99.9% background reduction ~ 400 events

Statistics dominated uncertainty

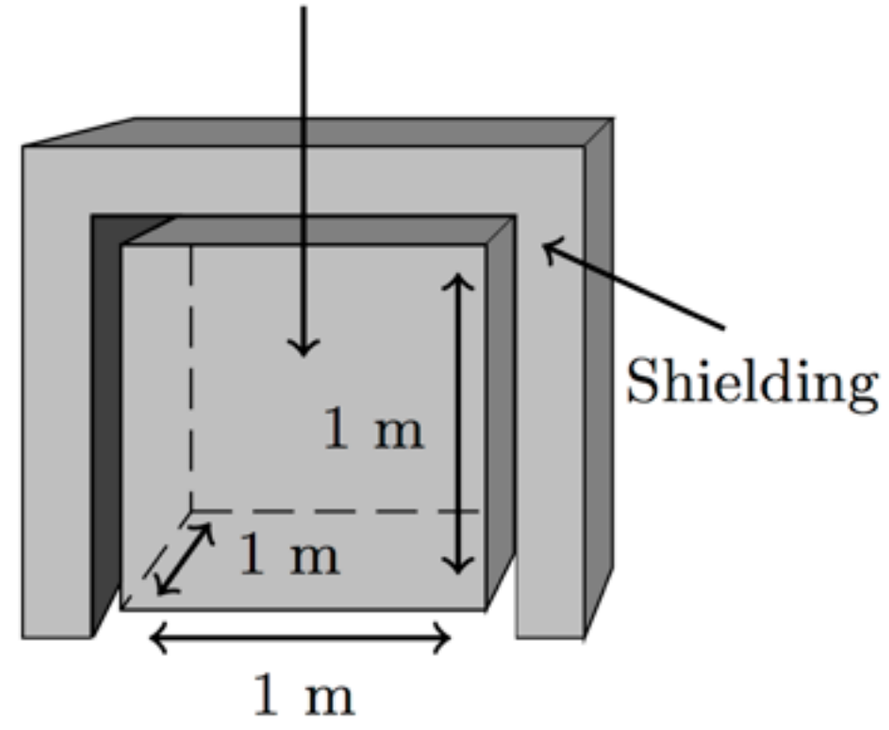
Sensitivity ~ 40 event signal yield

Need all (?) of these:

Active neutron veto

Neutron moderator

Directional information



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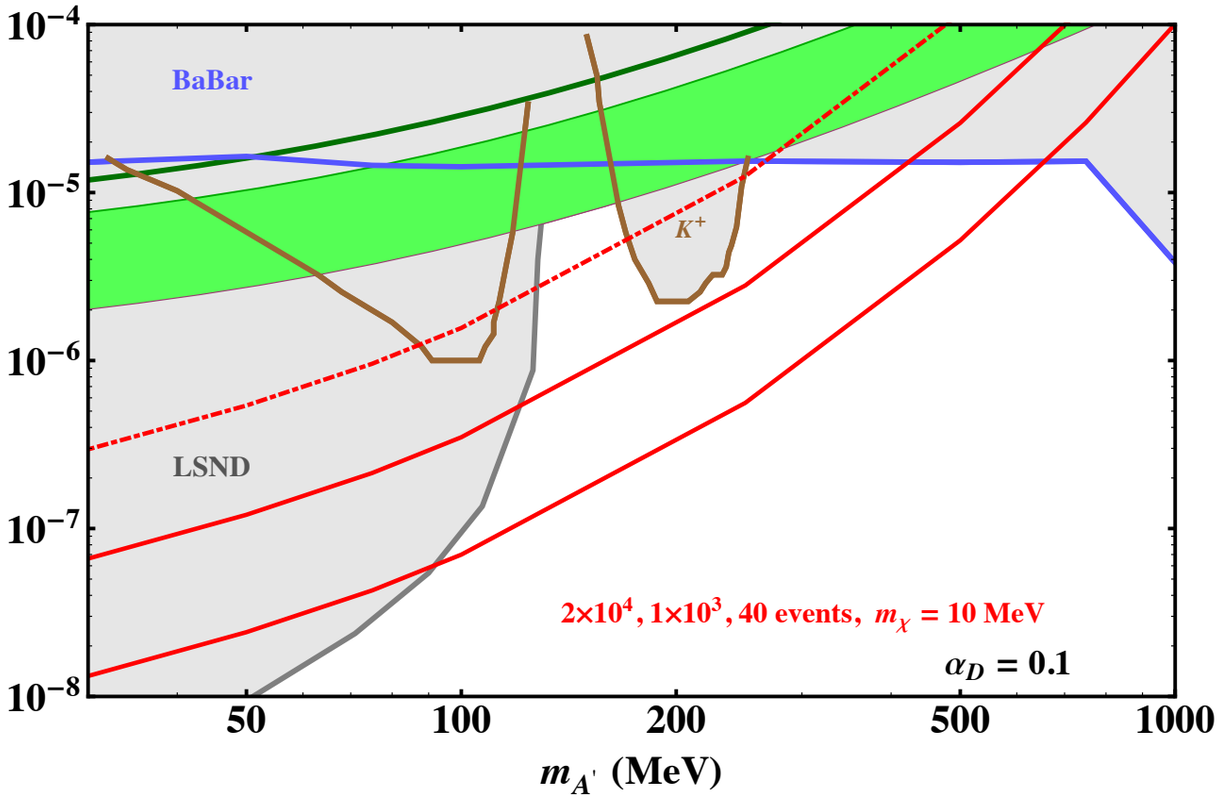
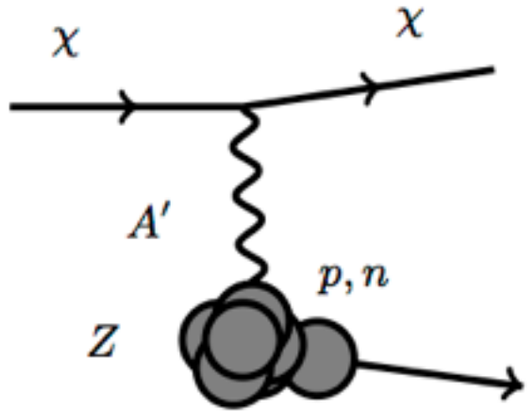
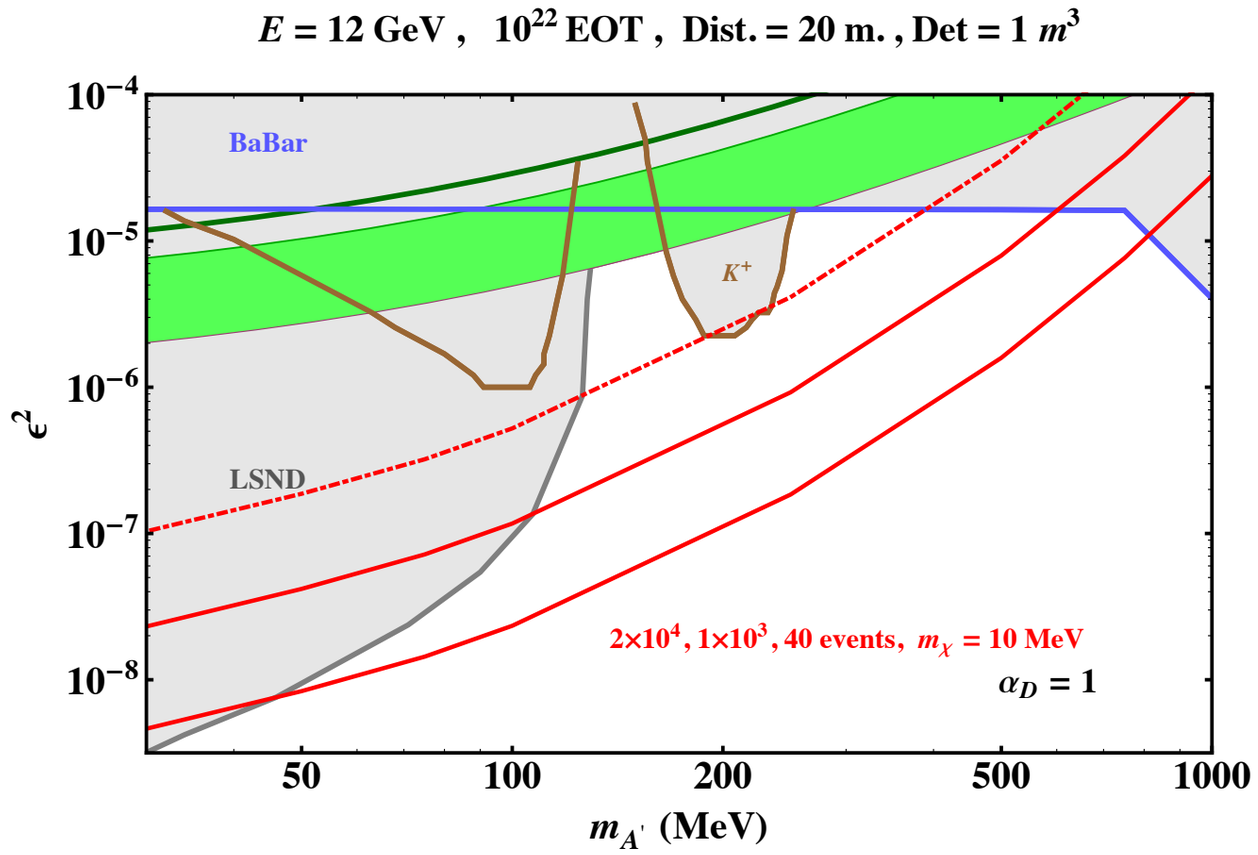




Quasi-elastic nucleon , CW beam

$\Delta = 0$



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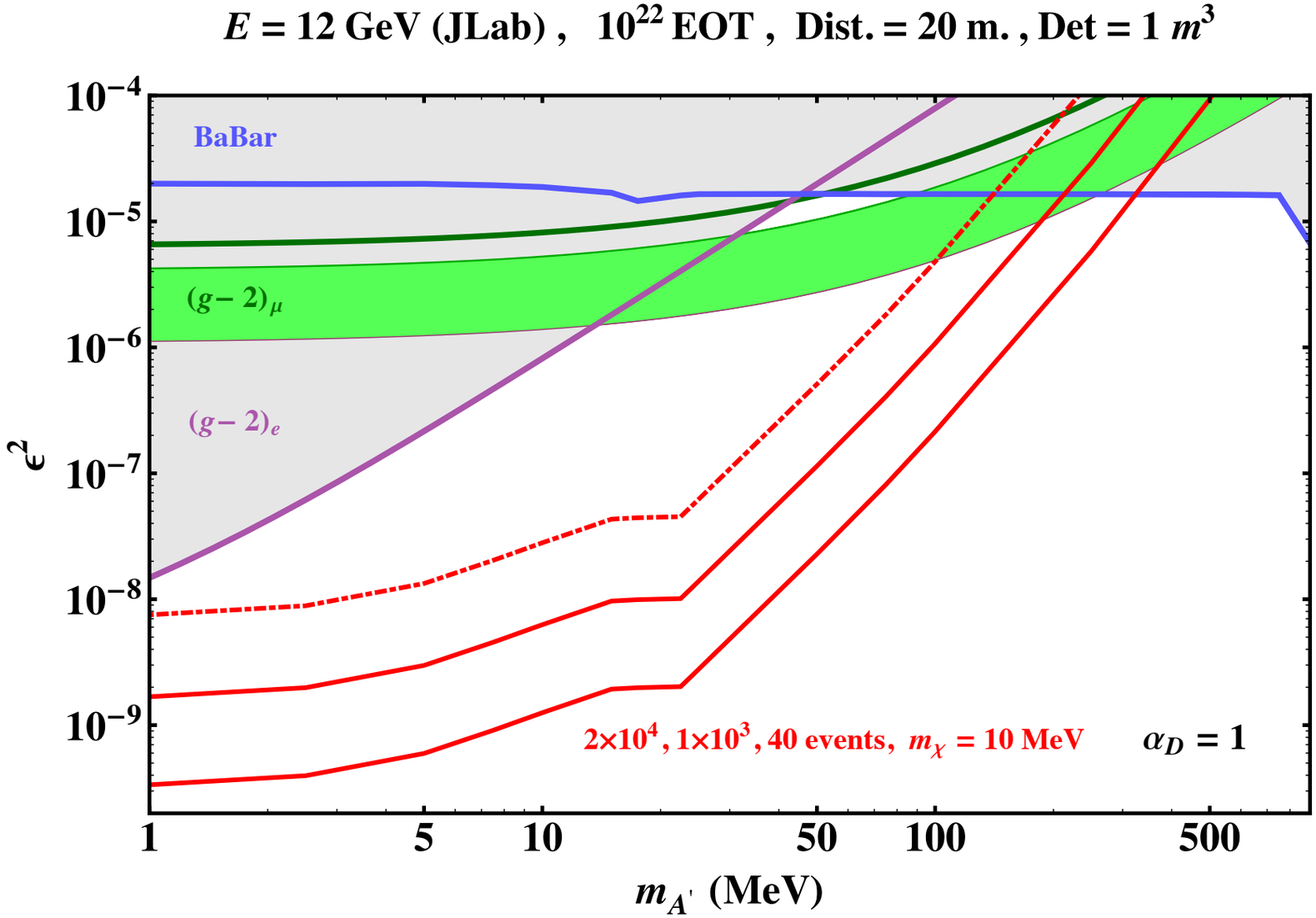
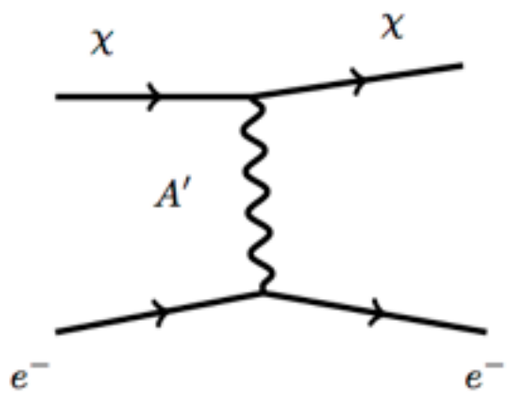
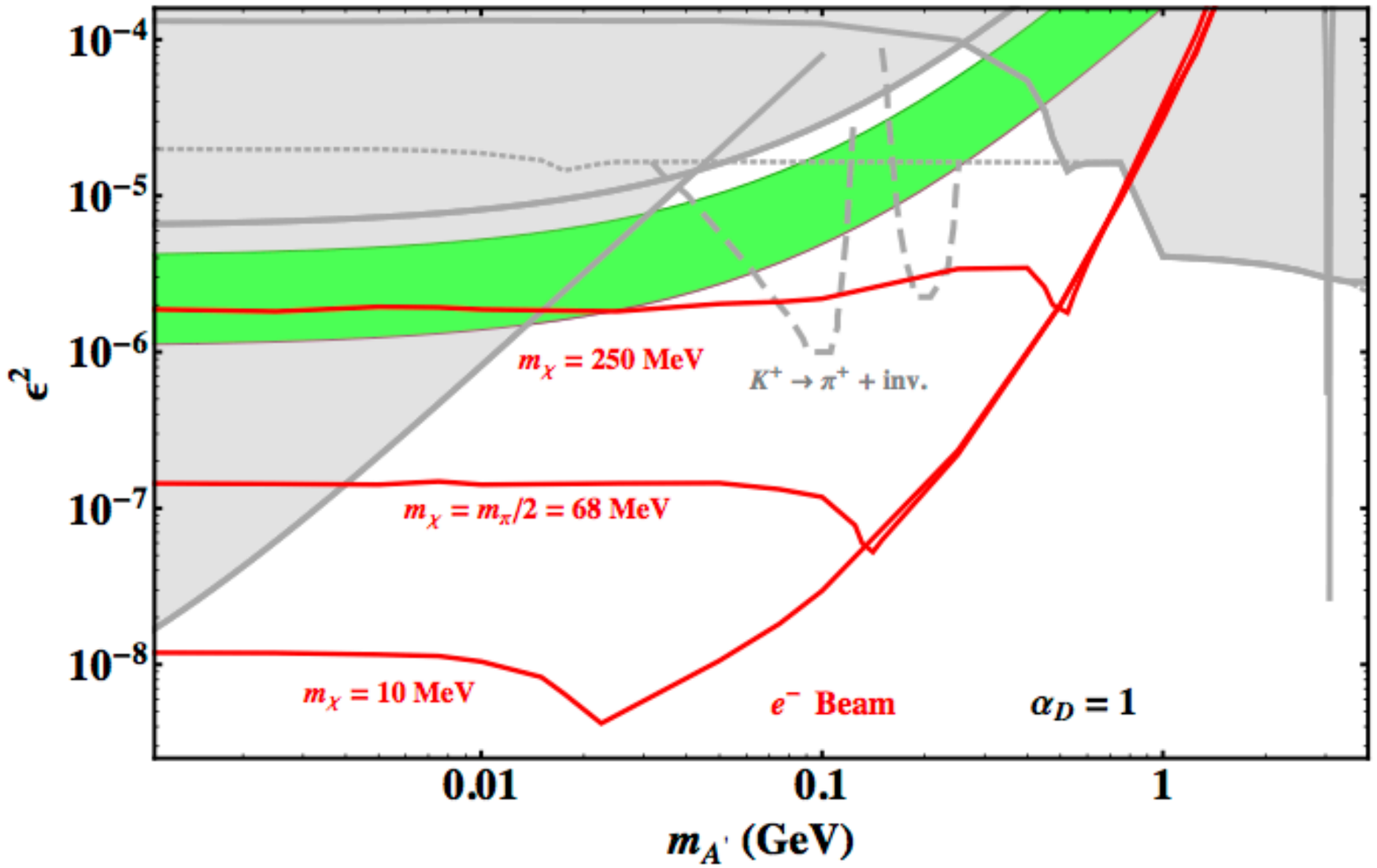


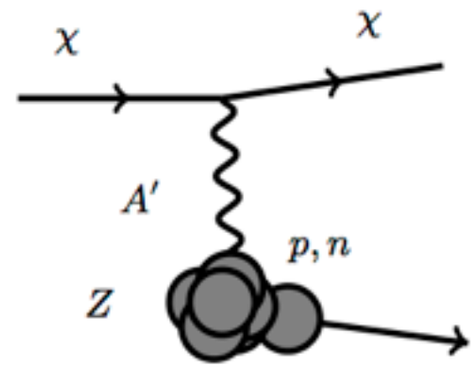


electrophilic scattering, CW beam $\Delta = 0$

Side Comment

Vary DM Mass





40 event yield contours

Overview

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- … *tomorrow*?
- BDX progress

V1.8
June 2, 2014

Letter of Intent to PAC 42

Dark matter search in a Beam-Dump eXperiment (BDX) at Jefferson Lab

The BDX Collaboration

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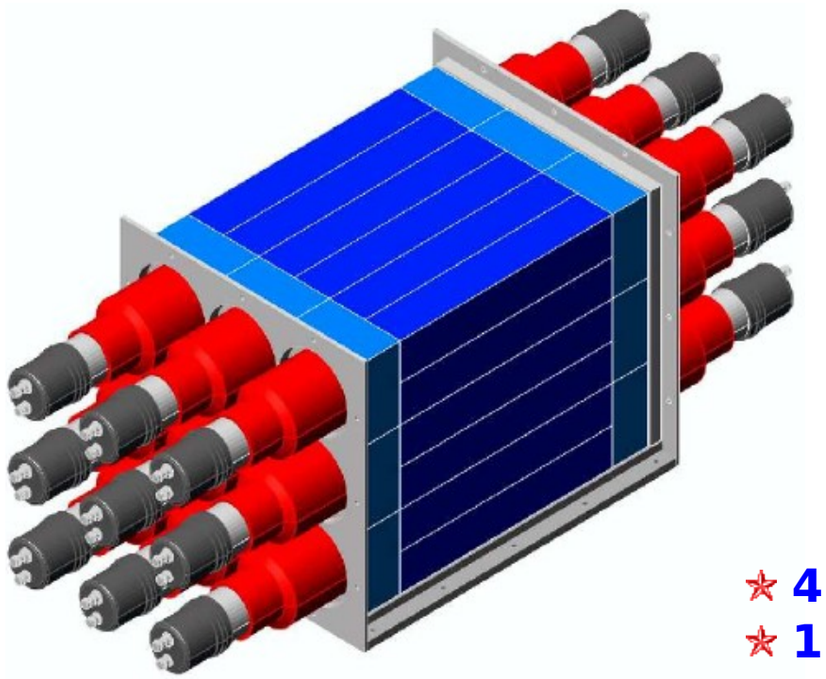
80+ members (Canada, US, UK, Italy)

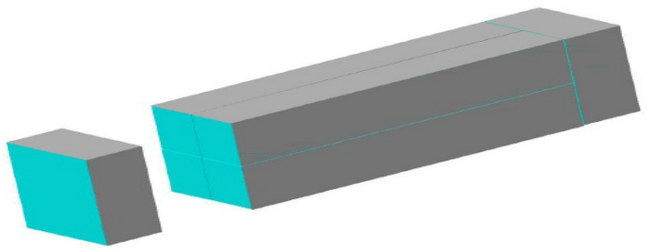
Test Run w/ Existing Detector:

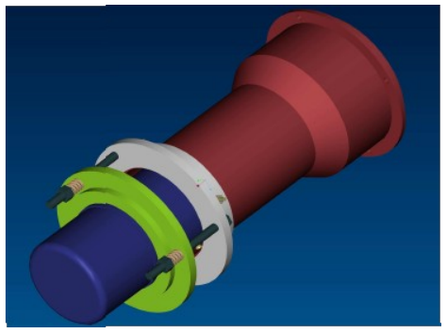


CORMORAD prototype

CORMORINO

scale $(1:3)^3$ ~3% m^3



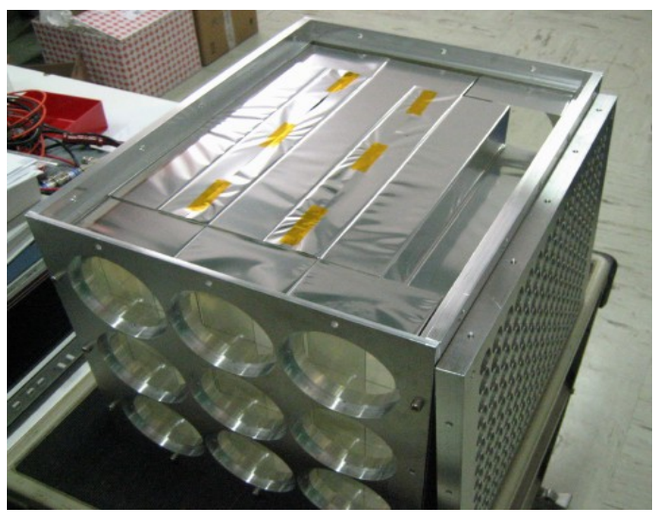


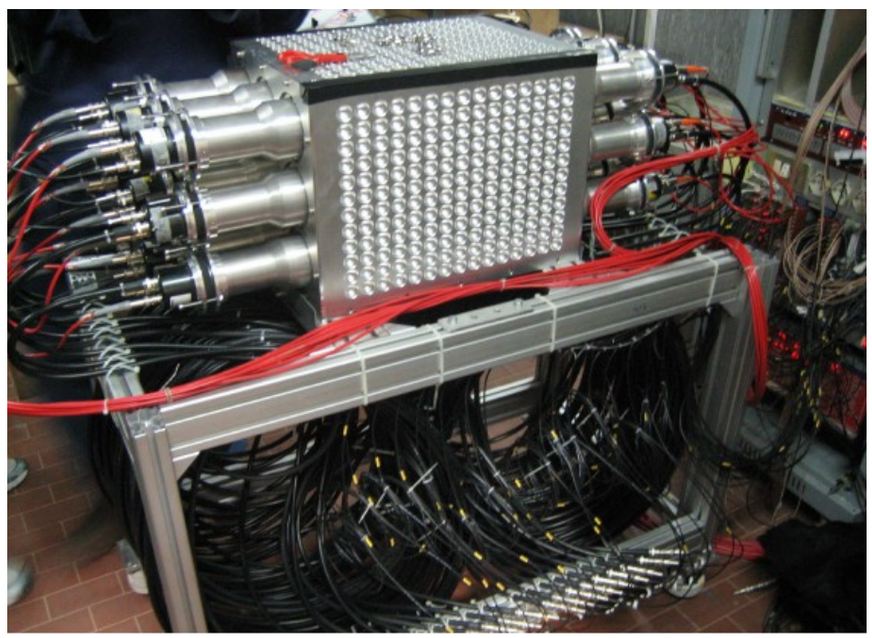
Prototype cell

- **4 30x5x5 cm^3 NE110 bars**
- **1 5x10x10 cm^3 NE110 block**
- **12.5 μm Gd foils wrapping**

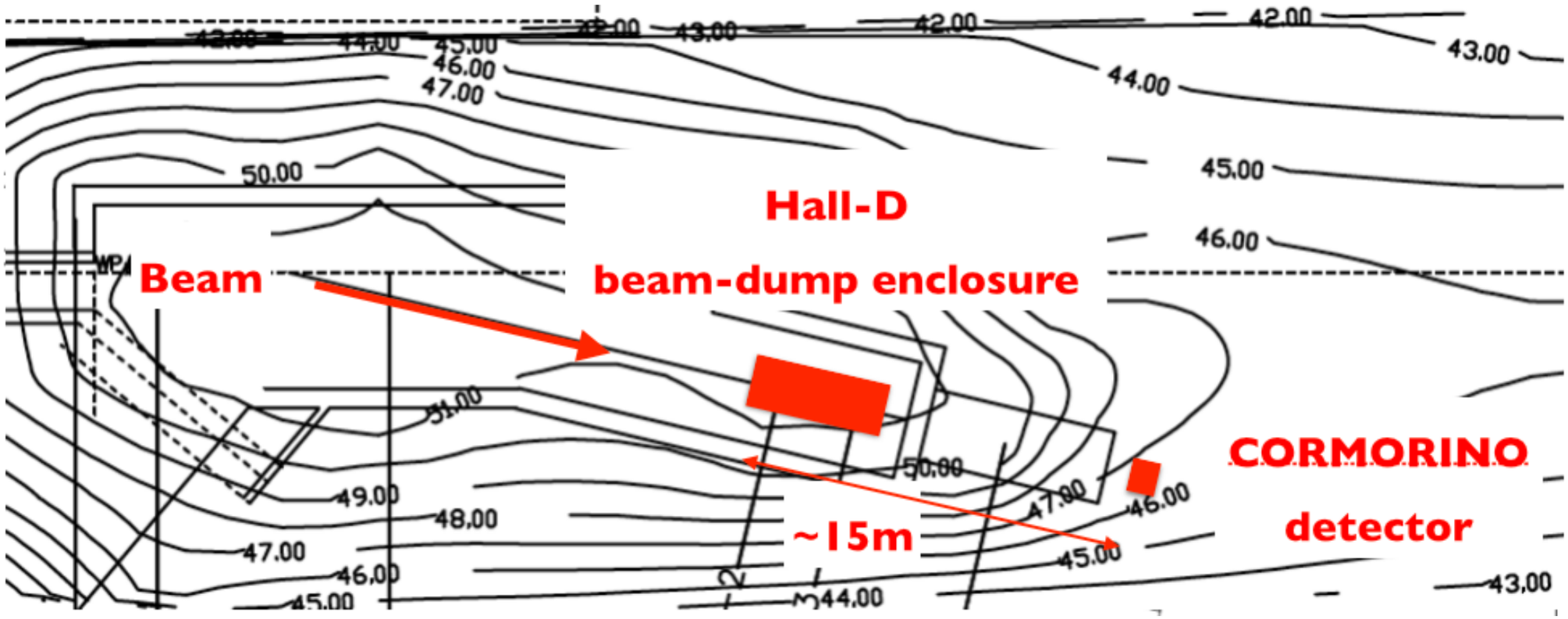
- **Light read-out: 18 Photonis XP2312 3" PMTs**

- **Size: 40 x 30 x 30 cm^3**





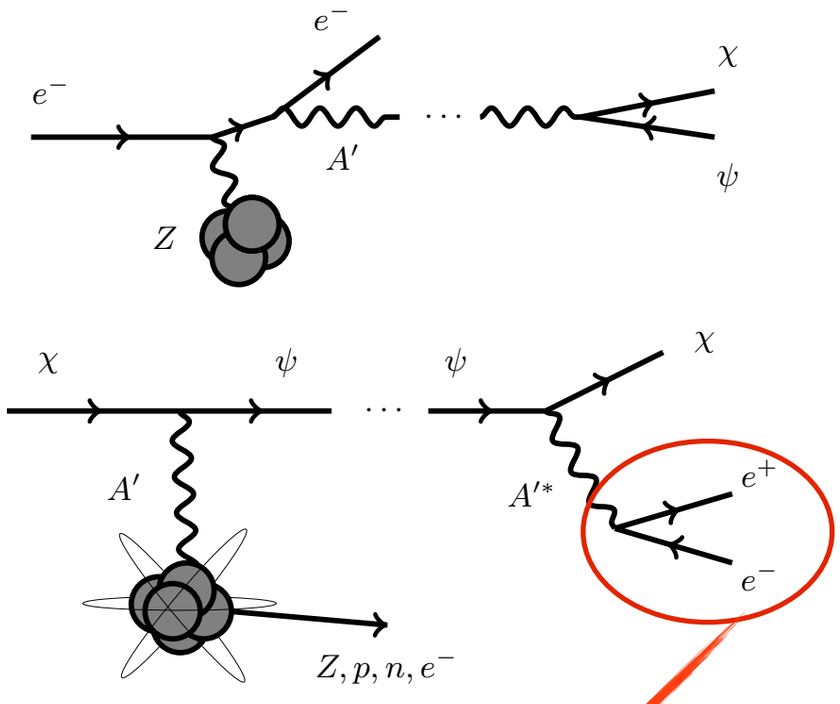
Test Run w/ Existing Detector:

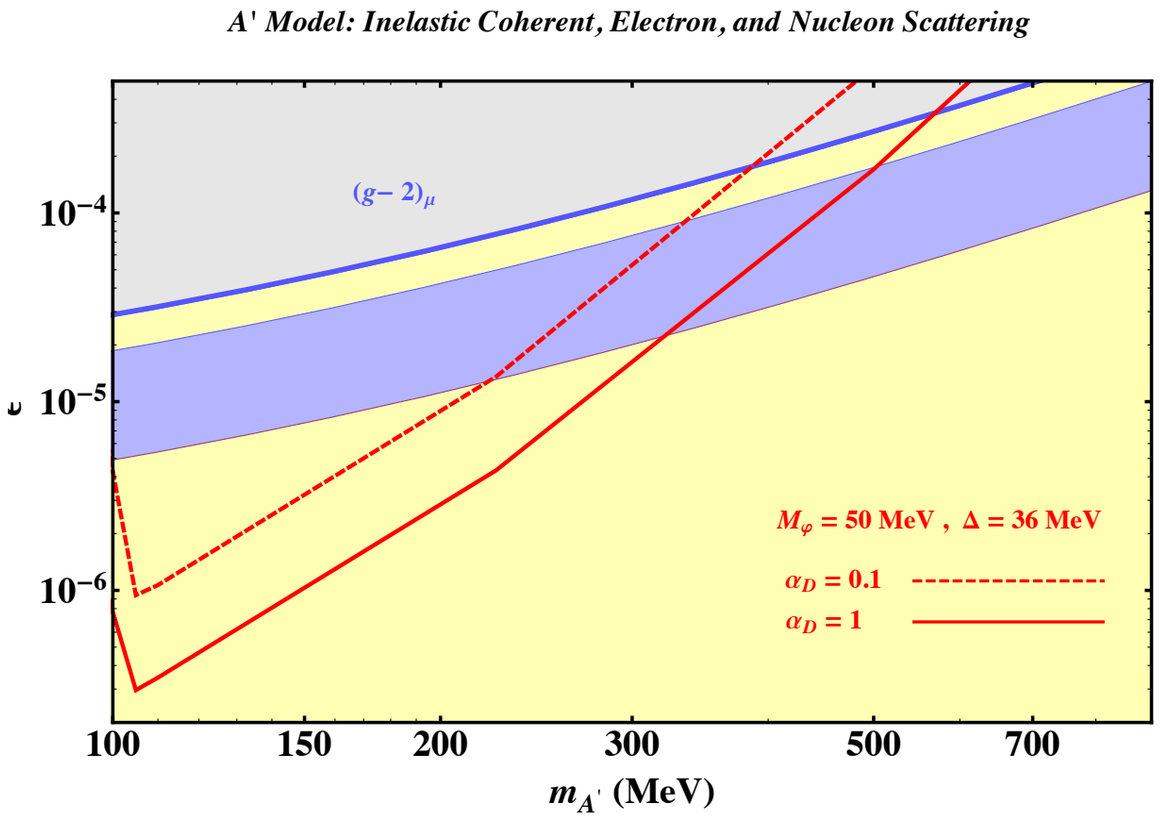


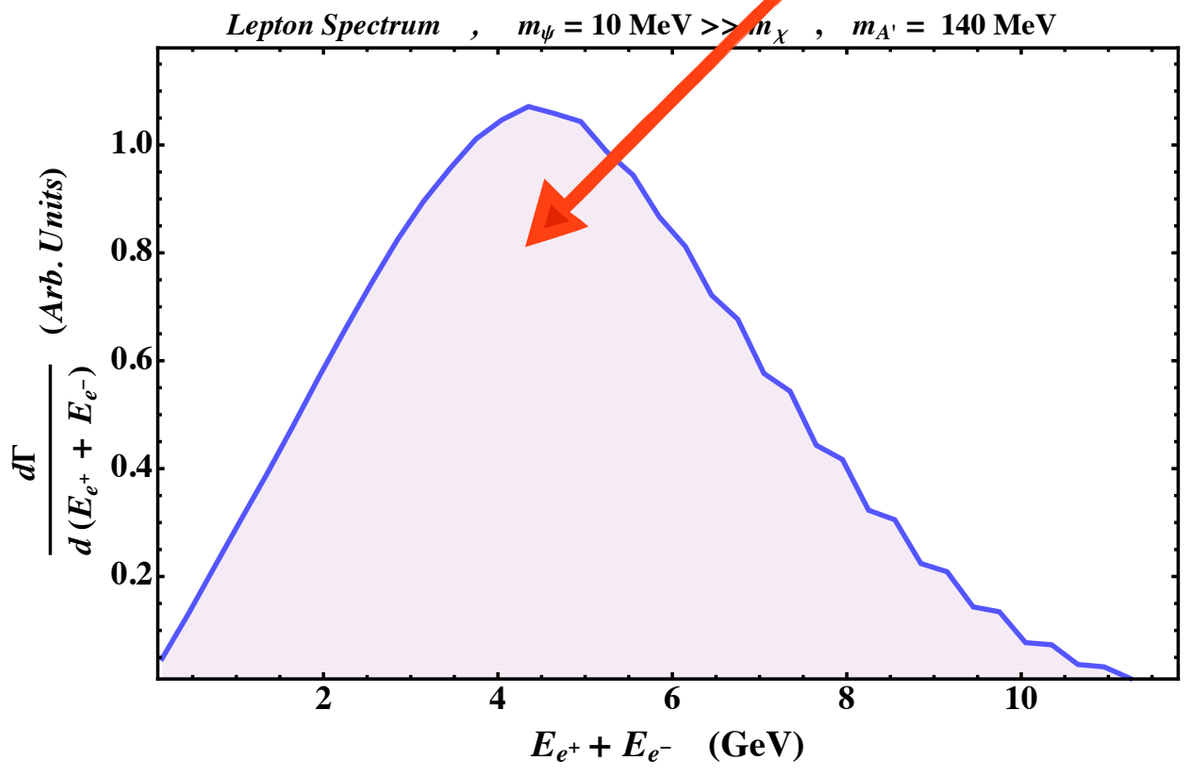
Hall D Test run w/ 10^{19} EOT w/ CORMORINO.

Can it cover new ground?

Test Run w/ Existing Detector:





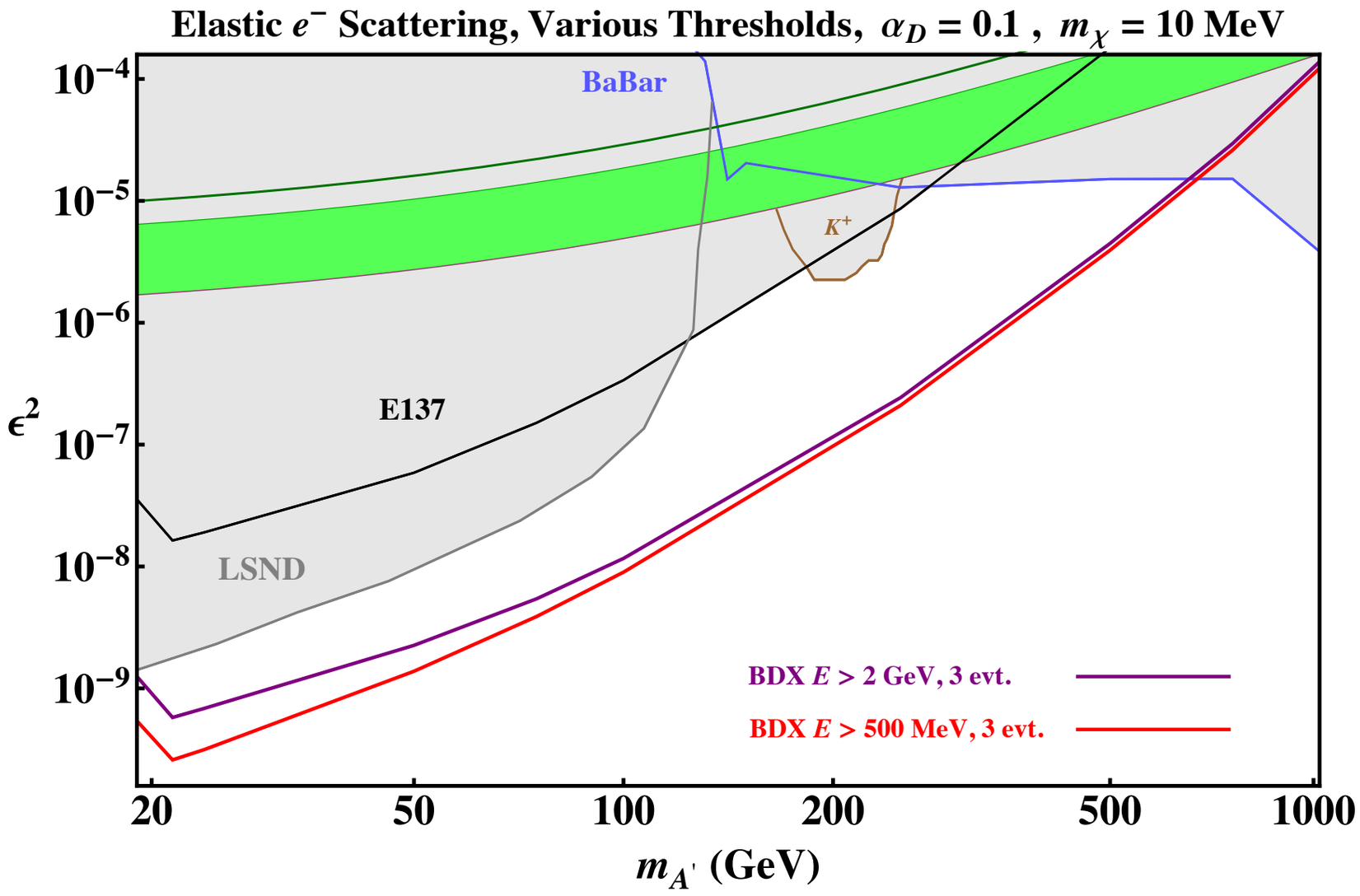


Hall D test run, CORMORINO

See $e^{\pm}$, recoil irrelevant!

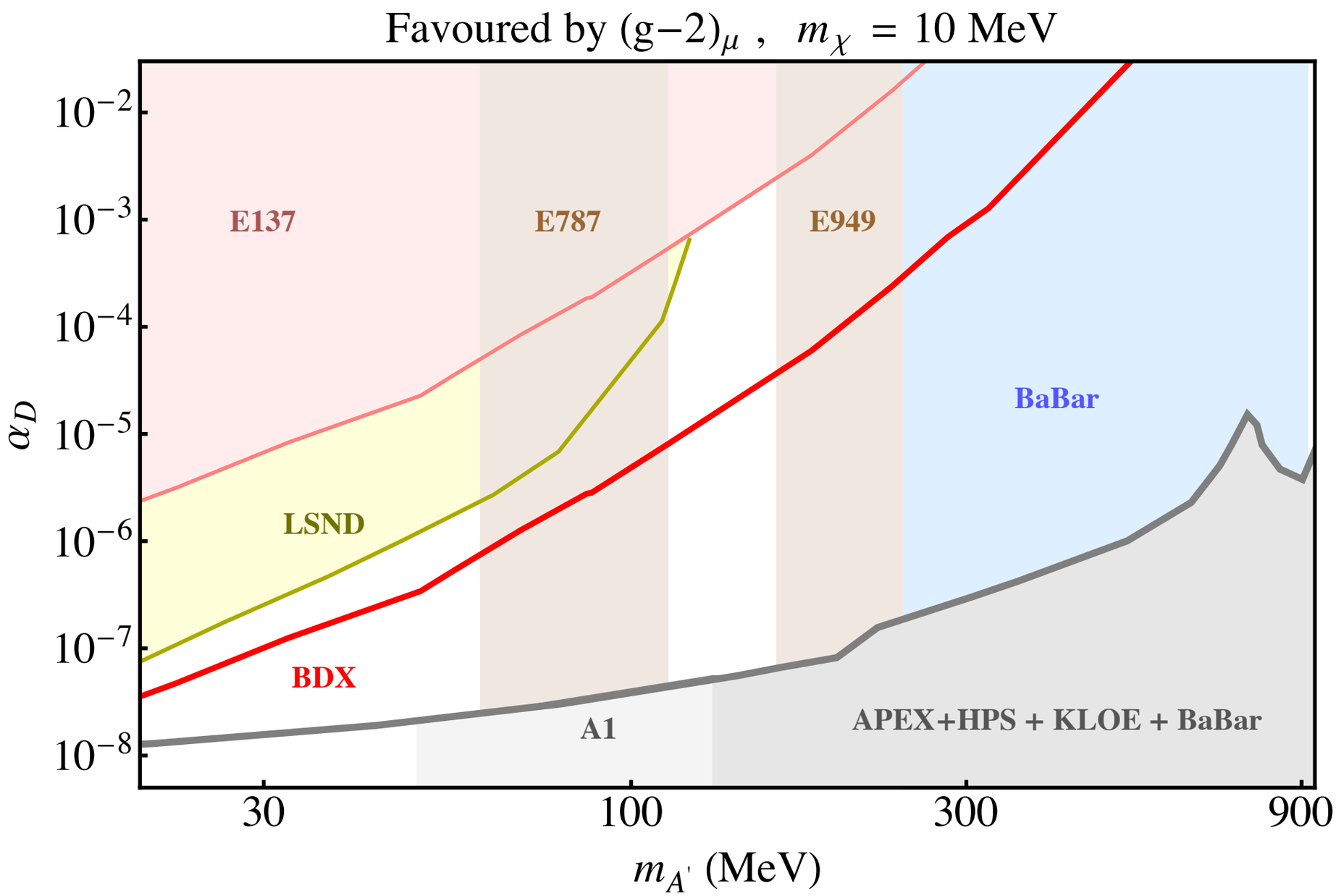
Sensitive to NP w/ only ~ $10^{19} e^-$

Ultimate BDX Reach for ~1yr



10^{22} EOT $\qquad$ $1\,\mathrm{m}^3$ detector

"Model Independent" $(g-2)_\mu$ Coverage



Summary

Electron fixed-target searches are powerful

High acceptance, negligible beam BG, reducible cosmic BG

Probe much viable MeV – GeV range

Dedicated experiment can extend sensitivity by orders of magnitude
Definitively cover (g-2)μ, complement proton and visible A' searches

Can run *parasitically* at existing facilities

JLab, SLAC, Mainz, DESY, Super KEK-B

Only the beginning

BDX positive review from JLAB PAC-42, full proposal underway

Thanks/Merci!